DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD 1975/158

A PRELIMINARY REPORT ON THE REGIONAL GEOLOGY OF THE EXMOUTH PLATEAU

by

N.F. Exon, J.B. Willcox and P. Petkovic

RECORD 1975/158

A PRELIMINARY REPORT ON THE REGIONAL GEOLOGY OF THE EXMOUTH PLATEAU

by

N.F. Exon, J.B. Willcox and P. Petkovic

CONTENTS

TABLES

FIGURES

PLATES

PLATES (Cont'd)

SUMMARY

The Exmouth Plateau and the adjacent continental slopes form a northeasterly-trending quadrangle with an area of 300 000 km^2 beyond the Australian Northwest Shelf in water depths ranging from 800 to 5000 m. This report combines 12 000 km of BMR seismic reflection profiles with 6000 km of company profiles, to yield an interpretation of the Phanerozoic geology of the area.

Initially all the major reflectors on the seismic sections were identified and tied together over the entire profile network. Then the reflectors were related to the geology of the Northwest Shelf by means of seismic tie-lines to shelf wells. Eight major reflectors were identified, and selected time-depth and time-thickness maps were constructed.

The dominant structural grain of the Plateau is northeasterly; the Kangaroo Syncline is a major downwarp lying 100 km northwest of and parallel to the Rankin Platform (Northwest Shelf), and the Exmouth Plateau Arch is a major rise 150 km northwest of and parallel to the Syncline. There is extensive normal faulting of the pre-Cretaceous sequence, with blocks downthrown to the west and tilted to the east. The structure is complicated by cross-cutting trends: easterly in the north, and northwesterly in the south. The same structural trends affect the entire sedimentary column, and are visible in the bathymetry.

The stratigraphy and the depositional environment of the sediments on the Exmouth Plateau have been inferred from seismic ties, consistency of seismic character, and structural comparisons between the Exmouth Plateau and the Northwest Shelf, and from palaeogeographical reconstructions for northwestern Australia.

Basement is overlain by up to 10 000 m of Phanerozoic strata. Little is known about the Palaeozoic sequence, which comprises half the Phanerozoic sequence in places, but shallow marine and terrestrial sedimentary rocks ranging in age from Cambrian to Permian are probably present. Overlying the Palaeozoic sequence is as much as 3700 m of Triassic shallow marine to fluvial sandstone, siltstone, and shale (Locker Shale and Mungaroo Beds), which is extensively block-faulted, presumably because of tension related to seafloor spreading. Unconformably overlying the uneven Triassic surface is up to 2000 m of Middle and Upper Jurassic pro-deltaic mudstone (Dingo Claystone) and Neocomian deltaic sandstone, siltstone, and mudstone (Barrow Group). It is believed that a northeasterly-trending spreading centre developed to the west in the Late Jurassic, separating this area from western Gondwanaland. At the same time a latitudinal transcurrent fault, with associated igneous intrusions, started to form the area's northern margin.

An average of 200 m of mid-Cretaceous shallow marine siltstone and mudstone (Winning Group) conformably overlies the Neocomian. Early in the Late Cretaceous a northwesterly-trending fault probably started to form the area's southwestern margin; it too was associated with igneous intrusions.

The mid-Cretaceous beds are unconformably overlain by a carbonate sequence, averaging 700 m in thickness, which ranges from Senonian to Recent in age. Two major hiatuses within the sequence are believed to be of Paleocene and Oligocene age. The Senonian-Maastrichtian carbonates were probably laid down in shallow water, and the Cainozoic carbonates in bathyal depths (more than 200 m). In the Late Cainozoic the Exmouth Plateau Arch formed, and collapse along old latitudinal fault-lines in the north gave rise to half-grabens south of marginal sub-plateaux.

Petroleum source rocks, especially pre-Cretaceous shales and siltstones, and reservoir rocks, especially Triassic and Neocomian sandstones, appear to exist in the Exmouth Plateau area. The depth of burial has probably been adequate to form hydrocarbons from Lower Jurassic and older source rocks. Numerous fault traps in Triassic sediments, analagous to those of the Rankin Platform, appear to exist. Other likely petroleum targets are stratigraphic traps in the Jurassic-Neocomian deltaic sequence. The area is potentially a major petroleum province.

INTRODUCTION

Seventy-three percent of Australian petroleum resources has been found on the continental shelves of Australia (Konecki et al., 1972), but the lesser known continental margins, particularly the rifted Atlantic-type margins which border the southern and western coasts.....'are areas of great sediment accumulation and thus may present great potential for petroleum resources. From what can be inferred from oceanographic studies of the yet-undrilled and unexplored offshore areas, it is conceivable that Atlantic-type margins may possibly possess orders-of-magnitude more petroleum resources than all the continental shelves in the world combined or, conversely, very little at all.' (Heezen, 1974).

Since the discovery of the Kingfish and Halibut Fields in the Gippsland Basin during 1967, the most significant Australian gas reserves have been found in the Rankin area of the Northwest Shelf. The initial successes on the Northwest Shelf, particularly oil on Barrow Island, led to the surge in exploratory drilling during 1970, which has since declined despite several further gas and minor oil discoveries.

Although regional seismic lines off northwest Australia have indicated that the prospective section and structures underlying the Northwest Shelf extend beneath the Exmouth Plateau, the considerable water depths have discouraged exploration beyond the shelf break. To date, all nearby wells have been drilled in water depths of less than 140 m; however, with the rapid advances being made in drilling, well completion and recovery technology, development of fields in more than 1000 m of water may be expected within the next decade (e.g. National Petroleum Council, 1969). Drilling vessels such as the SEDCO-445 (Anderson, 1974) which are equipped with blowout prevention stacks, can already drill commercial wells in water depths of about 650 m, and SEDCO-472, to be completed in 1977, is designed to drill in 1800 m of water with a 9000 m drill string (OGJ, 1975). Glomar Challenger has drilled a stratigraphic hole to 521 m in a water depth of 6243 m, as part of the Deep Sea Drilling Project (Scripps Institution of Oceanography, 1974). Lockheed Petroleum Services Ltd already offers a subsea well completion and production system with a water depth capability of 366 m, and future systems development by Lockheed and other companies should cope with several times this depth (Lockheed, 1973).

The Exmouth Plateau lies adjacent to the Northwest Shelf and is the second-largest marginal plateau of offshore Australia (Fig. 1). It covers 200 000 km^2 (Falvey & Veevers, 1974); an area of similar size to the Northwest Shelf and about 15 times larger than the Gippsland Basin. It forms a broad dome, culminating in 815 m water depth, 250 km offshore.

This report outlines the geology and structure of the Exmouth Plateau and examines its hydrocarbon potential. The principal sources of data are 12 000 km of reflection seismic profiles obtained by the Bureau of Mineral Resources (BMR) as part of its Continental Margin Survey, and 6000 km obtained by private enterprise and lodged with BMR under the requirements of the Petroleum Submerged Lands Act (1959-1969). The interpretation is supported by seismic refraction data from sonobuoys together with gravity and magnetic profiles and contour maps. Seismic lines obtained by the M/S Gulfrex (Gulf, 1973) have enabled tentative ties to be made to wells on the Northwest Shelf.

The seismic data are presented as a series of reflection-time maps showing the 'time-thicknesses' and 'time-depths' to each horizon. These are presented at a scale of 1:1 000 000 but have been worked at 1:250 000 in the central area where water depths are less than 1200 m.

The nomenclature used for the Plateau in this report is related to seismic reflectors as shown in Table 1.

Previous Investigations

General accounts of the physiography of the Exmouth Plateau region have been given by Fairbridge (1955) and Heezen & Tharp (1966). More recently Falvey & Veevers (1974) produced an exhaustive physiographic study of the Wharton Basin and the Exmouth and Scott Plateaux. Veevers, Falvey, Hawkins, & Ludwig (1974) presented a regional study of stratigraphy and structure of Exmouth and Scott Plateaux and adjacent deeps, using seismic data collected on board R/V Vema and R/V Conrad of Lamont-Doherty Geological Observatory and HMAS Diamantina of the Royal Australian Navy. Additional seismic data from the BMR sparker survey of the shelf was also used (Whitworth, 1969; Veevers, 1973).

The geology of the onshore Carnarvon Basin was described by Condon (1968) and of the onshore Canning Basin by Veevers & Wells (1961). The geology of the offshore portions of the Carnarvon and Canning Basins, which underlies the continental shelf, has been summarized by Thomas & Smith (1974) and Challinor (1970) respectively. Geophysical data in the offshore Canning Basin and the northernmost Carnarvon Basin were collected by Burmah Oil Company of Australia and associated companies and by BMR (Whitworth, 1969). In most of the Carnarvon Basin, initial exploration was carried out by Ampol, which was later joined by Caltex and Shell Development (Australia) Pty Ltd giving rise to West Australian Petroleum Pty Ltd (WAPET), which has been responsible for more recent exploration.

TABLE 1

m.y.	Age			Nomenclature in this report	Exmouth Plateau seismic reflectors	Reflectors after Veevers et al. (1974)	Reflectors on Rankin Platform after B.O.C.
	Pleistocene			Miocene-Recent			
	Pliocene						
	Miocene	late					T1
		middle					
20		early					
					A1	R2	T2
	Oligo.	late					
		early					
							E
40	Eocene	late		Eocene			
		middle			A2		T4
		early					
	Pal.	late					
					B		X
60		early					
	Cretaceous	Late	Maastrichtian	Senonian — Maastrichtian			
			Senonian: Campanian				
80			Senonian: Santonian				
					C	R3	D
			Senonian: Coniacian				
			Turonian				
			Cenomanian	Winning Group			
100		Early	Albian				F
			Aptian				
					D		Y
120			Neocomian	Barrow Group			
					E		H
140	Jurassic	Late	Tithonian	Dingo Claystone			
			Kimmeridgian				
			Oxfordian				
160			Callovian				Jc
		Mid.	Bathonian				
			Bajocian				J
180		Early					
200					F	R4	T
	Triassic	Late	Rhaetian	Mungaroo Beds			
			Norian				
			Carnian				
220		Mid.	Ladinian				
			Anisian				
		Early	Scythian	Locker Shale			
240					G		S
	Permian	Late	Tatarian	Permian			
			Kazanian				
		Early	Kungurian				
260			Artinskian				
			Sakmarian				
280	Carboniferous						
300							

9

EXMOUTH PLATEAU NOMENCLATURE

RECORD No 1975/158 WA/88-98A

A brief description and interpretation of water depths, Bouguer anomalies, magnetic anomalies, and reflection seismic records, collected off northwest Australia during the BMR Continental Margin Survey, has been given by Hogan & Jacobson (1975). A preliminary geological history and contour map of reflection time to a probable top Triassic or top Lower Jurassic interface were prepared by Willcox, Exon, Petkovic, & Petkovic (1975).

Stratigraphic information in the deep ocean basins adjacent to the Exmouth Plateau has been provided from holes drilled on Leg XXVII of the Deep Sea Drilling Project (Veevers, Heirtzler, et. al., 1974). A bibliography of papers dealing with deep-sea drilling in Australasian waters was provided by Veevers (1975).

Analyses of marine magnetic anomalies off Western Australia, on the Perth Abyssal Plain and in the Wharton Basin, have been used in reconstructions of Gondwanaland and attempts made to explain the structure of the west and northwest margin of Australia (Veevers, 1971; Veevers, Jones, & Talent, 1971; Sclater & Fisher, 1974; Markl, 1974; Veevers & Heirtzler, 1974).

Source of geophysical data

The reflection seismic data used in preparation of this report come from five sources:

(i) BMR Continental Margin Survey, 1970-1973 (CGG, 1975)

(ii) BMR geophysical survey of the northwest continental shelf, 1968 (Whitworth, 1969)

(iii) Esso Australia Ltd marine seismic survey of the Indian Ocean, offshore Western Australia, E71A, Dec. 1971-Jan. 1972 (Esso, 1972).

(iv) Gulf Research and Development Co. and Australian Gulf Oil Co. regional geophysical reconnaissance off the northern coast of Western Australia, conducted with the M/S Gulfrex from 28th May - 6th July 1972 (Gulf, 1973).

(v) Shell Development (Australia) Pty Ltd marine geophysical survey offshore Australia, conducted with MV Petrel from 7 June to 25 Aug. 1971 (Shell, 1972).

Seismic data collected on board HMAS Diamantina (see Veevers et al., 1974) have also been considered.

10

Primary navigational control for these surveys was given by satellite-Doppler systems. The ships' positions between satellite fixes were computed by linear adjustment of the dead-reckoned track for the Esso, Gulf, and Shell surveys, and by VLF navigation and linear adjustment of the sonar-Doppler track for the BMR 1968 and 1970-73 surveys. During the BMR 1970-73 survey the Sonar-Doppler system operated satisfactorily in deep water, using back-scatter of the sonar signal from the water mass beneath the ship. The off-shelf accuracy of the navigation of all the surveys is probably about 2 km, and this assumption is supported by the absence of major bathymetric and seismic misties at the intersections of seismic lines from different surveys. Post-survey processing of the BMR navigational data should lead to greater accuracy along Continental Margin Survey lines.

The seismic energy sources used on the Esso, Gulf, and Shell surveys were Maxipulse, Aquapulse, and air-guns, respectively. Twenty four-channel digital recording was used throughout. On the Continental Margin Survey the seismic energy source was a single electrode sparker with a discharge energy of 120 kJ. Six channels were recorded in analogue format. Further details of the equipment and its performance are given by Hogan & Jacobson (1975).

The gravity and magnetic anomaly contour maps (Pls.7, 8, and 9) were derived from the BMR Continental Margin Survey and the survey of the northwest continental shelf (Whitworth, 1969): for definition of gravity and magnetic anomalies see Appendix I. Magnetic and bathymetric profiles (Pl. 14) were plotted from Continental Margin Survey one-minute data tapes.

Reduction and presentation of geophysical data

The reflection seismic sections used in this interpretation have been processed and displayed as follows:-

(i) Esso and Gulf sections
12-fold and 24-fold Common Depth Point (CDP) stack with deconvolution and time variant filtering after stack: variable area display.

(ii) Shell Sections
2-fold CDP stack without corrections for moveout, produced on-line by an optical method: variable area display.

(iii) BMR 1968 data
Single-channel monitor sections produced on-line using EGG electro-chemical recorders.

(iv) BMR Continental Margin Survey Data
Single-channel monitor sections produced on-line using EPC electrosensitive recorders. Also a 6-fold stack of line 18/069, digitally processed by Geophysical Service Inc. for WAPET.

The seismic sections presented in Plates 13A to 13F have been reduced onto a common vertical scale although considerable variation in horizontal scale is still present.

The water depth data presented in Plate 2A are derived from Elac fathometer records recorded during the Continental Margin Survey and hand-digitized by Compagnie Generale de Geophysique (CGG, 1975), and directly from company seismic records. Recent studies have indicated that water depths derived from the Raytheon fathometer during the Continental Margin Survey are generally more reliable and show consistently shallower depths than the Elac values, the difference increasing linearly from 0 to 100 m for water depths from 0 to 6000 m. A correction graph is given in Appendix II.

Contouring of the 'time-thickness' and 'time-depth' maps have been carried out manually using approximate linear interpolation. Figures have been reduced and simplified from the corresponding plates. The gravity and magnetic anomaly contour maps were contoured by machine, using linear interpolation on a minimum curvature surface fitted to the data points. The regional reliability of the gravity and magnetic data can be gauged from the standard deviations of the misties at line intersections given by Hogan & Jacobson (1975) for Continental Margin Survey lines off northwest Australia. These were 4.1 mgal and 23.4 nT, respectively.

The reflection time associated with horizons in wells on the Northwest Shelf has been derived from the well velocity surveys (Appendix IV).

Acknowledgements

Plates accompanying this report were drafted by L. Hollands, L. Kerec, A.J. Maxwell and F. Simonis of the BMR drawing office.

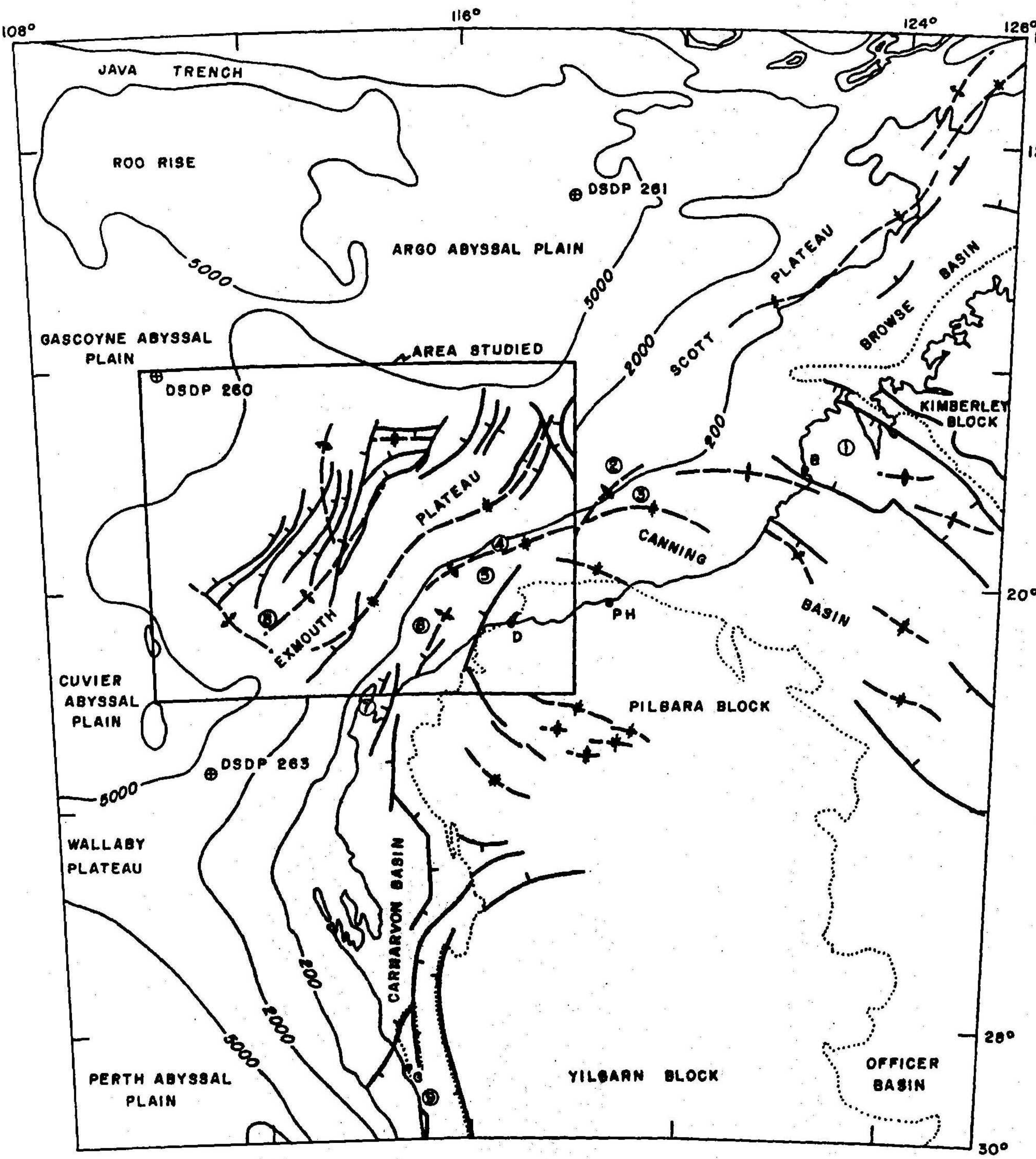
REGIONAL SETTING

Physiography

The Exmouth Plateau is an underwater extension of the Australian continent well to the northwest, into the Wharton Basin. To the north (see Falvey & Veevers, 1974; Also Fig. I) lies the Argo Abyssal Plain (average depth 5700 m), to the northwest the Gascoyne Abyssal Plain

12

FIG. 1



① Fitzroy Trough	-200- Isobath (metres)
② North Turtle Arch	Fault, with displacement
③ Bedout Sub-basin	Fault, displacement unknown
④ Rankin Platform	Anticline
⑤ Dampier Sub-basin	Syncline
⑥ Barrow Sub-basin	Phanerozoic basin
⑦ Exmouth Sub-basin	
⑧ Exmouth Plateau Arch	
⑨ Perth Basin	

TECTONIC SETTING

SCALE AT 24°S

200 0 200 400 600 kilometres

13

From Tectonic Map of Australia (1971), Veevers and Johnstone (1974) and by authors

RECORD No 1975/158

WA/B8-88A

(average depth 5700 m), and to the southwest the Cuvier Abyssal Plain (average depth 5070 m). Between the Argo and Gascoyne Abyssal Plains is the Roo Rise, and between Cuvier and Perth Abyssal Plains is the eastern Wallaby Plateau. North of Roo Rise and Argo Abyssal Plain is the Java Trench, which is more than 6500 m deep in places. Below the Exmouth Plateau is the lower continental slope, extending almost to abyssal plain depths; separating the lower slope from the abyssal plains in many areas are the continental rise, foothills, or swales (Falvey & Veevers, 1974).

Falvey & Veevers subdivided the area by using changes of slope. Below the shelf break they defined an upper slope with in inclination of 1-2° and a lower slope with an inclination of 3-5°. The inner Exmouth Plateau (their 'plateau proper') lies below the upper slope and has gradients of less than 0.5° and the outer Exmouth Plateau (their 'plateau edge zone') lies above the lower slope and has gradients of up to 3°. Using this system the coastal margin of the Plateau lies between 800 and 1400 m, and the seaward margin between 1300 m and 3100 m, depending on the depths of slope breaks. The area of the Plateau so defined is 200 000 km^2.

Because our interests are not primarily physiographic we have used a simpler definition, regarding the Plateau as lying between 200 m and 2000 m (see Fig. 4). This means that, as compared to Falvey & Veevers, we have included the upper slope in the Plateau, and excluded much of the northern deeper-water part of the Plateau. We follow them in defining the eastern limit of the Exmouth Plateau as lying east of Swan Canyon (new name) where there is a continuous continental slope and no plateau; farther east is the steadily widening Scott Plateau. Landward of the Exmouth Plateau is the broad, largely featureless Northwest Shelf.

As we have used the term, the area of the Exmouth Plateau is about 150 000 km^2. However, our study deals with the sedimentary pile beneath the sea bottom between a water depth of 200 m and the foot of the lower slope, which increases the total area considered to about 300 000 km^2.

Geology

The Exmouth Plateau region (see Fig. 1) is a northwesterly extension of the Australian continent consisting of about 10 km of Precambrian schist, gneiss, and metamorphic basement rocks overlain by as much as 10 km of Phanerozoic sediments. The basement sequence is probably equivalent to that of the Pilbara Block, and we regard the Phanerozoic sedimentary sequence as an offshore extension of the Carnarvon Basin.

There is lateral continuity with Phanerozoic sediments of the Carnarvon Basin to the south (Exmouth Sub-basin), southeast (Barrow Sub-basin), and east (Dampier Sub-basin), and with Phanerozoic sediments of the Canning Basin to the east. Northward, westward, and southwestward the Phanerozoic sediments of the Exmouth Plateau terminate abruptly in the continental slope, beyond which is oceanic basement overlain by Cretaceous and Tertiary deep-ocean sediments.

The Exmouth Plateau sedimentary sequence appears to be generally similar to that of the Carnarvon Basin, so we have included the plateau sequence in the basin, although the basin was arbitrarily terminated by Thomas & Smith (1974) at the outer edge of the continental shelf. The Carnarvon Basin proper is about 300 000 km^2 in area, to which the Exmouth Plateau region adds another 300 000 km^2. Typical offshore Carnarvon Basin sequences of the Northwest Shelf are illustrated in Figure 2.

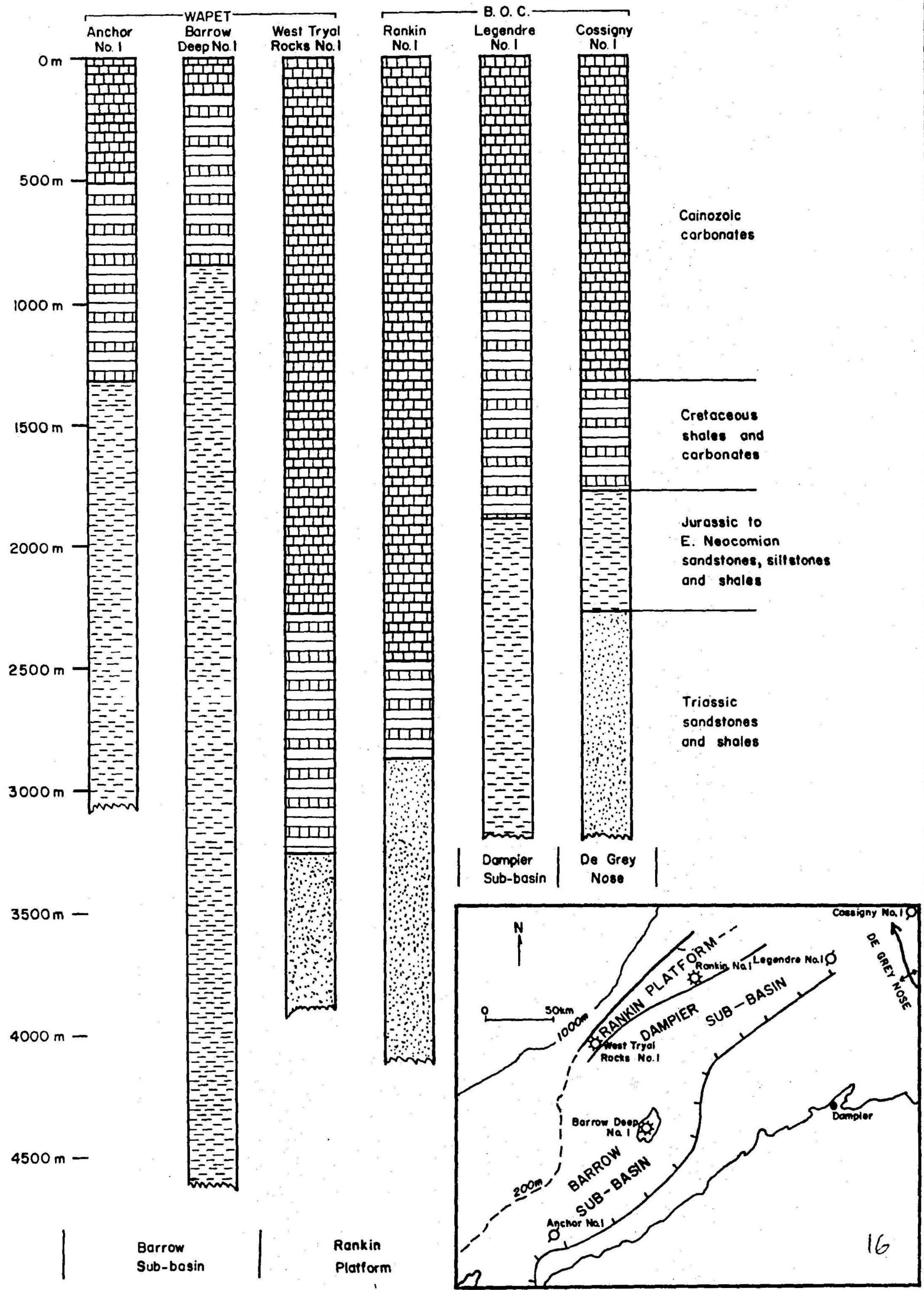
The Carnarvon Basin was recently described by Thomas & Smith (1974) as an elongate crustal depression which straddles the central Western Australian coastline between the towns of Geraldton and Dampier. It is a large complex structure containing sediments ranging in age from Silurian to Recent which lap eastward onto the Precambrian Shield. The southern part of the basin consists largely of Palaeozoic sediments veneered by Tertiary and Cretaceous sediments, but the northern part contains thousands of metres of Triassic, Jurassic, and Neocomian sediments. In the offshore part of the northern area, between the coast and the Exmouth Plateau, thick post-Neocomian Cretaceous, Tertiary, and Quaternary shelf sediments overlie the older rocks. The major stratigraphic sequences in wells in different parts of the northern Carnarvon Basin are shown in Figure 2.

Thomas & Smith (1974) described the north-northeasterly-trending Exmouth Sub-basin as a 'fault-bounded Mesozoic trough.....Possibly 5000-7000 m of marine and fluviatile sediments, mainly Jurassic in age, are contained in this elongate half-graben. The pre-Cretaceous structure of the sub-basin is dominated by a strong pattern of faults trending north-northeast.....The southeastern limit of the Exmouth Sub-basin is defined by the Rough Range Fault, a major normal fault with a pre-Cretaceous throw of up to 3000 m down-to-the-west.' The Exmouth Sub-basin grades northeastward into the Barrow Sub-basin and there is no clear separation of the Exmouth Sub-basin from the Exmouth Plateau area.

Thomas & Smith stated that the northeasterly-trending Barrow and Dampier Sub-basins, between which there is no clear division, 'form a Jurassic-Cretaceous downwarp bounded to the east by major down-to-the-basin faults and

FIG. 2

NORTHWEST SHELF SEQUENCES



RECORD No 1975/158

WA/B8-86A

to the west by a regional high trend in Triassic and Early Jurassic rocks (Rankin Platform and its southerly extension). The Exmouth, Barrow, and Dampier Sub-basins were probably a depositional entity throughout the Jurassic, with the Barrow and Dampier Sub-basins remaining linked into the Neocomian. The Barrow and Dampier Sub-basins are bounded to the east by the complex Enderby, Flinders, and Long Island Fault Systems'. The faults trend generally north-northeasterly in the Barrow Sub-basin and northeasterly in the Dampier Sub-basin.

Thomas & Smith believed that the Exmouth-Barrow-Dampier Trough 'formed early in the Jurassic by block faulting in a tensional regime, possibly related to the break up of Gondwanaland. From Middle Jurassic to Early Cretaceous (Neocomian) there accumulated at least 5000 m of marine, deltaic and fluvial sediments. Beneath this relatively simple downwarp is thought to be a framework of faulted Permian, Triassic, and Early Jurassic sediments which have been penetrated in wells only on the high eastern and western flanks of the trough. Modern seismic data indicates over 15 000 m of sedimentary section in parts of the Barrow Sub-basin.'

The Rankin Platform (e.g. Kaye, Edmond, & Challinor, 1972; Powell, 1973; Thomas & Smith, 1974), a northeasterly-trending structural high in Triassic and Lower Jurassic sediments, separates the Exmouth Plateau area from the Dampier Sub-basin and much of the Barrow Sub-basin. Up to 3000 m of Cretaceous, Tertiary and Quaternary sediments (see Figs. 3 & 9) is draped over the platform, which lies beneath the edge of the continental shelf. The stratigraphy of the three wells nearest the Exmouth Plateau is illustrated in Appendix IV (Figs. A, B, C). The platform is cut by numerous en-echelon normal faults with trends varying in the main from northeasterly to northerly, and vertical displacements of as much as 1000 m. Middle and Late Jurassic sediments have not been recorded on the horst blocks of the Rankin Platform. Kaye et al. (op. cit.) believed that the main period of faulting was in the Late Triassic, and Thomas & Smith (op. cit.) indicated that fault movement in the northern Carnarvon Basin as a whole continued from the Late Triassic into the Early Jurassic.

The intracratonic Canning Basin (Fig. 1) covers about 600 000 km^2 of which 165 000 km^2 lies offshore, inside the 200 m bathymetric contour. It is a gentle downwarp containing about 6000 m of Palaeozoic sediments over much of its extent. The geology of the offshore Canning Basin, in which structural trends are largely westerly, has been described by Challinor (1970) and by BMR Basins Study Group (1974). Onshore the basin is dominated

17

by the northwesterly-trending Fitzroy Graben which developed during the Carboniferous and Permian. The graben, in which the depth to basement may reach 19 000 m in some places, contains up to 8000 m of Upper Palaeozoic sediments overlain by about 700 m of Triassic and Jurassic sediments. It continues offshore in a north-northwesterly direction, and is bounded by the Beagle Bay Fault to the north, and the Dampier Fault to the south (Challinor, 1970).

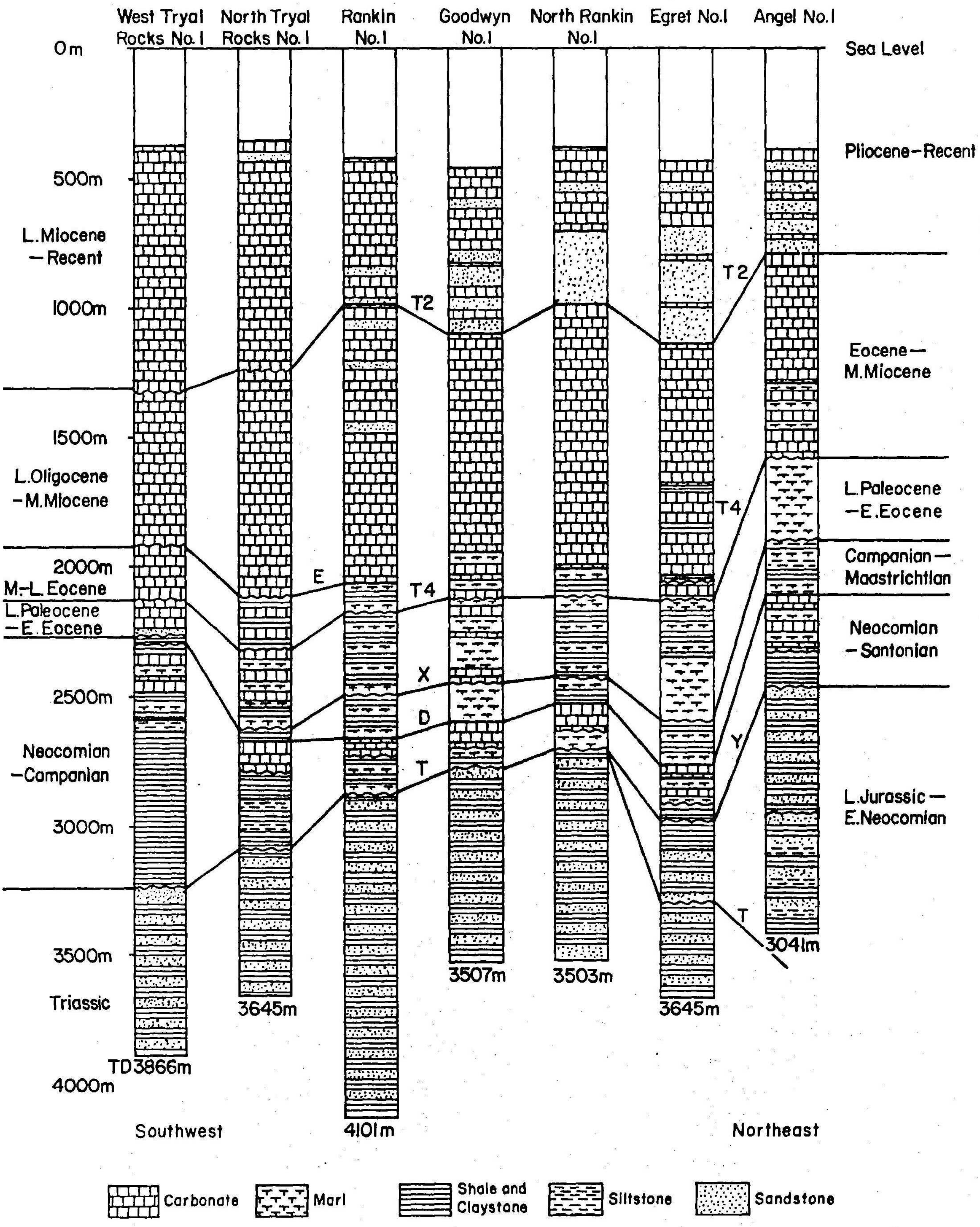
The easterly-trending Bedout Sub-basin, which forms the western part of the offshore Canning Basin, is separated from the Rankin Platform and the Beagle Trough of the Dampier Sub-basin by the northeasterly-trending North Turtle Arch (Fig. 1). However farther north no subdivision between the Canning Basin and the Exmouth Plateau area is apparent. In the Bedout Sub-basin up to 1500 m of Lower Jurassic non-marine sediments rests unconformably on older sedimentary and volcanic rocks, and is overlain by about 2000 m of marine Upper Jurassic, Cretaceous, and Tertiary sediments.

The oceanic areas around the Exmouth Plateau were related to the continental geology by Veevers & Johnstone (1974). At DSDP Site 263 in the Cuvier Abyssal Plain southwest of the Exmouth Plateau (Fig. 1) about 700 m of neritic claystone of Aptian-Albian age appears to rest on basement. This is part of the Winning Group which later (Late Cretaceous and Cainozoic time) sank to abyssal depths. It is overlain by about 100 m of turbidite-deposited Upper Cainozoic ooze. At DSDP Site 260 (Veevers, Heirtzler et al., 1973), northwest of the Exmouth Plateau, about 150 m of Albian and Upper Cretaceous deep-sea clay and ooze rests on oceanic basement. At DSDP Site 261, northeast of the Exmouth Plateau, about 400 m of Upper Jurassic and Cretaceous deep-sea clay rests on oceanic basement. At both sites (260, 261) about 170 m of turbidite-deposited Upper Cainozoic ooze overlies the Cretaceous sequence. At all three sites most of the Tertiary is absent (see Davies, Luyendyk, Kidd, & Weser, 1975 for discussion).

The Exmouth Plateau itself was a normal part of the Carnarvon Basin until Cainozoic time, and a Palaeozoic and Mesozoic sequence of continental and shallow marine sediments probably underlies the younger sequences. During the Cainozoic the plateau sank to its present depth and was covered by bathyal carbonates.

Petroleum geology

As a petroleum province the Exmouth Plateau appears to be a natural extension of the northern Carnarvon Basin including the Rankin Platform. The northern Carnarvon Basin contains gas, gas-condensate, and oil fields, with gas predominating on and near the Rankin Platform and oil at Barrow Island. 18



19

WELL CORRELATIONS ALONG RANKIN PLATFORM

RECORD No 1975/158

E50/B8-42A

The major gas fields of the Rankin Platform area, North Rankin, Goodwyn, West Tryal Rocks, and Angel, are large by world standards. The estimated reserves of raw natural gas (proven plus speculative) in these fields plus the small Pasco Island field, in mid 1975 were 433 x 10^9m^3, from which 54 x 10^6m^3 of liquified petroleum gas could be extracted (Petroleum Newsletter No. 62). More than 45 x 10^6m^3 of well condensate could also be extracted from the gas (Petroleum Newsletter No. 60). The great bulk of the petroleum is trapped in horst blocks in highly porous, permeable sandstones of the Upper Triassic Mungaroo Beds, which are capped by Cretaceous shales, and are believed to derive their hydrocarbons largely from laterally juxtaposed Jurassic shales. The horst blocks formed in the Late Triassic and Early Jurassic and petroleum probably migrated into them in the Late Cretaceous and the Cainozoic. Kaye et al. (1972) stated that other objectives in the area are Lower Triassic, Jurassic, Lower Cretaceous, and basal Tertiary sandstones,and Upper Cretaceous carbonates. As yet no production facilities have been established on the fields of the Rankin Platform.

Barrow Island was declared a commercial oilfield in 1966. At the end of 1974 initial oil reserves were estimated as 40 x 10^6m^3 of which 42 percent has been produced. Initial gas reserves were 6 x 10^9m^3 of which 30 percent had been produced and flared off (Petroleum Newsletter No. 60). According to Crank (1973) 98 percent of production comes from the Aptian-Albian Windalia Sand Member of the Muderong Shale. Crank stated that the Windalia Sand Member is a high-porosity low-permeability sandstone oil reservoir found only on Barrow Island. Structural trapping occurs in a gentle north-plunging anticline faulted along its southern boundary. The reservoir is capped by siltstones of the Windalia Radiolarite. Other oil (and associated gas) shows come from sandstone in the Early Cretaceous and Late Jurassic sequences. Sandstones in the Jurassic Dingo Claystone produced large quantities of gas in Barrow Deep No. 1 well drilled in 1973-74. The major source beds are believed to be shales in the Jurassic and Cretaceous sequences. Crank (op. cit.) stated that the Barrow Island anticline started to form in Aptian time, that major arching occurred very late in the Cretaceous or early in the Paleocene, and that much of the migration of oil into the Windalia Sand Member must have occurred in the Tertiary.

The geological history and the sedimentary sequence of the Exmouth Plateau seem to be similar to those of the inshore northern Carnarvon Basin, at least until the Late Cretaceous, so it appears valid to make use of information from the Northwest Shelf when considering the petroleum prospects of the plateau.

20

PHYSIOGRAPHY

The Exmouth Plateau is a northwesterly extension of the Australian continent beyond the Northwest Shelf, and is elongated northeasterly parallel to the coast. We regard the plateau proper as being bounded by the 200 and 2000 m isobaths (a less rigorous definition than that of Falvey & Veevers, 1974), and eastwards by Swan Canyon (new name) which means that its area is about 150 000 km^2 (see Fig. 4). The lower continental slope extends downward to between 4500 and 5000 m, and when this is included the area of the continental margin related to the Exmouth Plateau is about 300 000 km^2. The physiography of the area is largely structurally controlled, but is modified by the cutting of canyons, and by other erosional and depositional processes.

The Northwest Shelf (Fig. 4) falls fairly steadily northwestward away from the land to the bounding 200 m isobath, although there are local rises which reflect deep structure. It has formed by prograding of Tertiary carbonate sands away from the continent and is at present a zone of winnowing and transport rather than deposition (Jones, 1971). The average width of the shelf in this area is about 100 km.

The upper continental slope falls with an average inclination of 1° toward the northeasterly to northerly-trending Montebello Trough (Falvey & Veevers, 1974). The Montebello Trough has a northerly gradient of about 0°20' and debouches into the northeasterly-trending Montebello Canyon (new name). Falvey & Veevers stated that there is no evidence of large-scale sediment transport in the trough, which tends to follow a broad depression in the deep (Traissic) structure (compare Figs. 4 and 5). They suggested that the trough is 'possibly a broad crustal deflection caused by the asymmetrical load of the sedimentary prism of the prograded shelf and shelf edge zone'. There is no thickening of Jurassic and Cretaceous sediments towards the trough (Fig. 7), as there would be if a depression had existed at the time, supporting the idea that it developed later, during the Tertiary.

About 250 km west-northwest of Barrow Island, and 100 km west of Montebello Trough, is a north-northeasterly trending culmination of the Exmouth Plateau, about 8000 km^2 of which lies above the 1000 m isobath; the minimum water depth is about 815 m. The axis of this culmination, the Exmouth Plateau Arch, can be traced for nearly 400 km, and it and the Montebello Trough dominate the Exmouth Plateau. The topographic axis closely reflects the deep structure (compare Figs. 4, 5, and 6), which hence appears to have controlled it.

21

BATHYMETRY

50 0 100 km

Thousand metre contour

Two hundred metre contour

One hundred metre from line

Twenty metre contour, shallower than 200 metres (Jones, 1973)

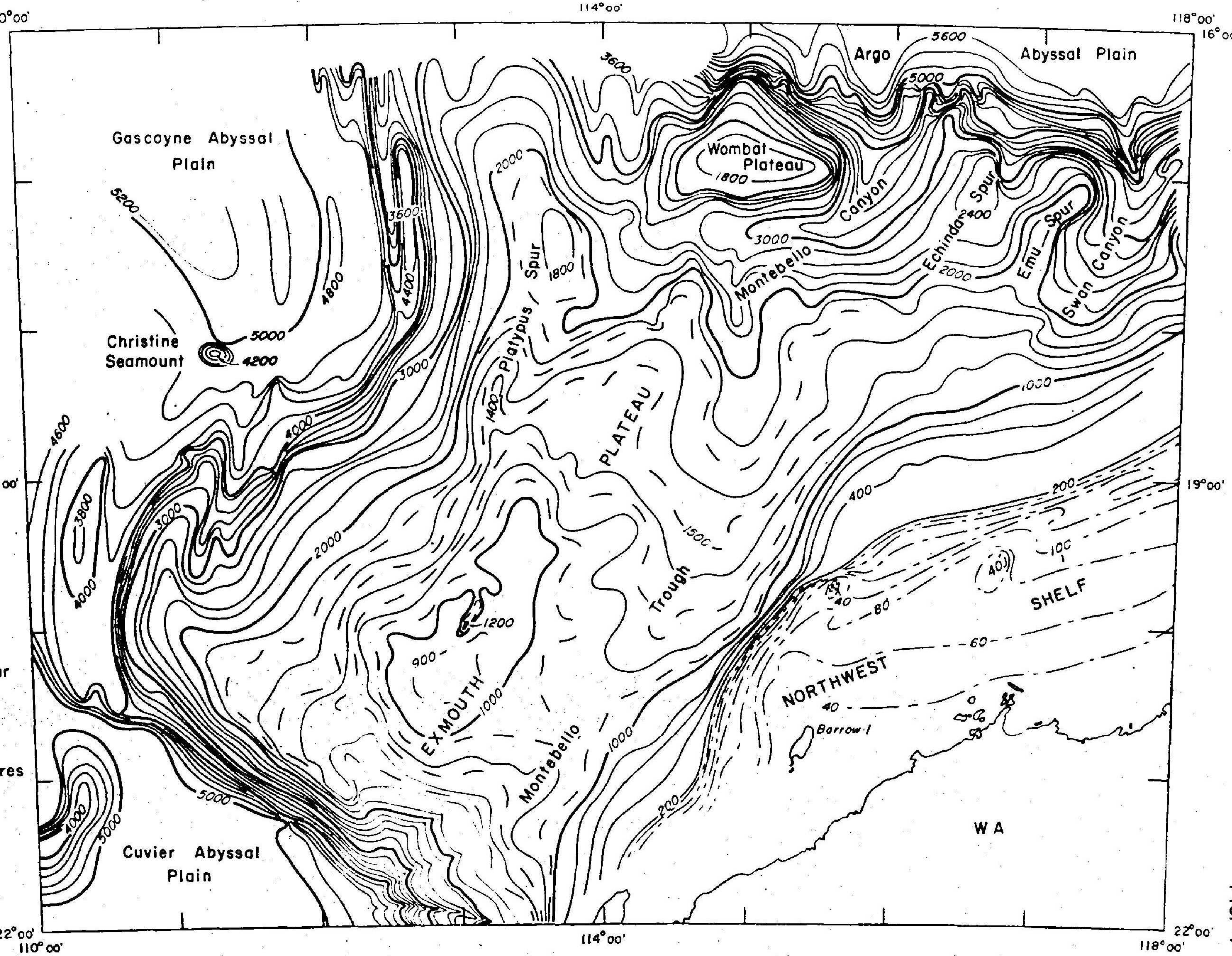


FIG. 4

The margins of the plateau are linear and steep, suggesting faulted origins. The southwestern margin of the area (Fig. 4) is a long straight northwesterly-trending slope with an average inclination of 3-5°. The north-western margin is more complex, with various indentations superimposed on a gentle curve, concave-outward, whose trend varies from northeasterly to northerly. Its average slope is about 3°. The northern margin is highly complex, with a general north-northwesterly trend, which is cut by blocks with northerly to north-northeasterly trending sides. Slopes as steep as 17° mark the outer edge of this margin (Falvey & Veevers, 1974).

Despite the complexity of the upper part of the northern margin, the foot of the continental slope is fairly straight (Fig. 4). Major features from west to east are Platypus Spur, Wombat Plateau, Montebello Canyon, Echidna Spur, Emu Spur, and Swan Canyon, all being new names. The Platypus Spur forms a northern extension of the Exmouth Plateau and can be traced northward for more than 200 km into water deeper than 3000 m. Wombat Plateau rises to 1620 m below sea level, and is separated from Exmouth Plateau by a trough more than 2600 m deep. It is elongated latitudinally, and that portion above 2000 m measures about 100 km by 50 km. It is separated from Platypus Spur to the west and Echidna Spur to the east by northerly-trending depressions. Montebello Canyon to the east is an extension of Montebello Trough. Echidna Spur and the adjacent Emu Spur are north-northeasterly trending extensions of the Exmouth Plateau, and both can be traced for more than 100 km before they disappear in water depths of around 3000 m. Farther east is the north-northeasterly-trending Swan Canyon which is depressed by some 1500 m relative to the Emu Spur.

These features of the northern margin are caused by block-faulting generally trending northerly to northeasterly, but the southern margin of the Wombat Plateau was formed by an easterly-trending half-graben.

The largest canyons are along the northern margin, and there are also several canyons along the margin in the extreme south. Most of the canyons appear to be inactive today (Falvey & Veevers, 1974).

GRAVITY AND MAGNETIC ANOMALIES

Hogan & Jacobson (1975) have provided detailed descriptions of Bouguer and magnetic anomaly maps of offshore northwest Australia based on Continental Margin Survey data. The magnetic, free-air, and Bouguer anomaly contour maps, at 1:1 000 000 scale (Appendix 1; Pls. 7, 8, and 9), accompanying this report combine data from the Continental Margin Survey with data from Lines 04/144, 04/146, 04/092 and 04/099 of the 1968 sparker survey (Whitworth, 1969).

Magnetic total field profiles and bathymetric profiles (Pl. 14) have been plotted from Continental Margin Survey one-minute data tapes.

The free-air anomalies on the continental shelf, central Exmouth Plateau, and abyssal plains have average values of approximately zero, indicating that the region as a whole is almost in isostatic equilibrium. The negative values on the outer continental slope result almost entirely from abrupt variations in water depth. The Bouguer anomalies exhibit regional gradients across the upper and lower continental slopes, which are attributed to crustal thinning beneath the continental margin. Values range from +30 mGal at the shelf break to + 250 mGal on the abyssal plains. Crustal thicknesses with respect to sea level have been computed from gravity values on Line BMR 17/068 (Appendix III). Because compensation generally occurs beneath bodies of at least 100 km across, the crustal thicknesses which were computed each hour (about 16 km) should strictly be filtered to remove wavelengths of less than 100 km. However, average values beneath the continental shelf and Exmouth Plateau indicate crustal thinning of about 4 km. If a 'standard crustal thickness' of 33 km is assumed the crustal thicknesses computed for the shelf and Plateau are 23 and 19 km, respectively.

The Bouguer anomalies show no evidence of a major fault along the shelf break, and this is consistent with our study of the seismic sections which show the shelf to be made up of a thick sequence of prograded sediments. The short-wavelength component of gravity anomalies correlates with the structure of the pre-Middle Jurassic rocks (pre-Seismic Horizon F) over most of the area. This is particularly apparent over the Rankin Platform and adjacent sub-basins, and 50 km north of North West Cape where a Bouguer anomaly low correlates with a depression in the 'top of Triassic' (Horizon F) reflector. The magnetic anomalies on the shelf increase in wavelength towards the west in response to progressive deepening of magnetic basement, presumably the Pilbara Block, towards the shelf break and beneath the Exmouth Plateau. The intense anomaly at the eastern extremity of BMR 17/068 (Pls. 7 and 14) correlates with the western margin of the Pilbara Block outcrop.

The broad, northeasterly-trending Bouguer anomaly low of 20 mGal relative amplitude lies over the Montebello Trough and indicates 1-2 km of additional sediments here, compared to the Plateau crest. The negative free-air anomalies are contributed to partly by the difference in water depth, and partly by the additional sediments. The negative free-air anomaly also indicates that the area is not in exact isostatic equilibrium, and the greater sediment load must be partly supported by the crust.

24

Broad low-amplitude magnetic and free-air anomalies over most of the Plateau probably arise from the thick sediment cover and a fairly uniform depth to basement. The shortest-wavelength anomalies observed on the magnetic profiles (Pl. 14) have widths of 20 km, which indicate basement irregularities or susceptibility contrasts about 7 to 10 km below sea level.

The relatively short-wavelength, magnetic anomalies over the western margin of the Plateau are caused by shallow igneous basement. The free-air anomaly ridge and short-wavelength magnetic anomalies along the southwest margin correspond with a zone of upturned beds of Palaeozoic, Triassic, and Jurassic strata (Pl. 3B, Fig. 7) and with igneous bodies associated with a major fault. However, part of the free-air anomaly is undoubtedly caused by an edge effect across the steep escarpment which delineates the southwest edge of the Plateau.

The northern edge of the Exmouth Plateau (as defined herein), along latitude 18°S, is associated with a step in the Bouguer anomalies and with the division between long-wavelength, low-amplitude, free-air and magnetic anomalies on the Plateau, and shorter-wavelength, high-amplitude anomalies to its north. In the area north of 18°S the free-air anomalies almost duplicate the bathymetry - showing weak highs on Platypus and Emu Spurs, a pronounced high on Wombat Plateau and a trough over the half-graben along its southern side. They reflect the combined gravity effects of variations in water depth and the relative elevations of sediments and basement within faulted blocks, which are supported by the crust.

In the northern area the magnetic anomalies show several large dipole-like features. In general, their crests lie between latitudes 16° and 17°S and overlie igneous bodies along the northern side of Wombat Plateau and the lower continental slope. Eastward from 118°E the anomalies trend northeasterly, then northerly, following the lower continental slope, and farther north extend over Scott Plateau (see Hogan & Jacobson, 1975). The northerly-trending magnetic anomaly high west of the 'Wombat half-graben' is also related to relatively shallow igneous basement. The largest dipole has an amplitude of 800 nT and has both its crest and trough displaced 30 km north of Wombat Plateau and the 'Wombat half-graben', respectively (see Pl. 13B, BMR 18/008). The total field profile shows it consists of a long-wavelength component derived from a source deep within the crust, probably related to crustal transition at the continental margin, and a short-wavelength component derived from a source at 5 to 10 km depth. The short-wavelength component appears to be related to outcrops of igneous basement on the northern edge of the Wombat Plateau and to structures deep within the half-graben. The easterly elongation of the magnetic trough along latitude $17^{\circ}20'$S is coincident with the axis of the half-graben. Farther east on Shell Lines N209 & N210, two other elongated magnetic lows also show an approximate correlation with grabens. On the magnetic anomaly map these troughs appear to be a continuous feature which has been offset along northerly-trending transcurrent faults on meridians 115°30', 116°30', and 117°00'E. The trough can be clearly traced eastward to the Rowley Shoals area on the 1:2 500 000 map described by Hogan & Jacobson. Other transcurrent faults may occur across the western end of the 'Wombat half-graben' and along meridians 113°30'E and 112°00'E.

The general trends of the gravity contours on the Plateau are consistent with the fault patterns interpreted from seismic sections. The southwestern edge of the Plateau is formed by a zone of intense northwest-trending faults which gave rise to the steep slope; the northwestern margin formed from the downthrow of numerous basement blocks towards the abyssal plain along north-northeasterly-trending faults; and the northern margin formed by interaction of north-northeasterly and easterly-trending faults which resulted in the formation of several grabens and sub-plateaux.

STRUCTURE AND THICKNESS MAPS

Structure contour and thickness maps of the area have been prepared at a scale of 1:1 000 000 in terms of reflection (two-way) time. More detailed contour maps at 1:1 000 000 scale (but prepared originally at 1:250 000 scale) give additional information on the central, most prospective area. This central area lies in the shallowest water, which adds to its economic importance. The maps of the entire area are presented as plates and as page-sized figures, and those of the central area as plates. Data maps showing the values plotted (to enable the contouring to be carried out) are included as plates. True structure contour and thickness maps, calculated by using the seismic velocities of Appendix IV, will be presented by Willcox, Exon, & Petkovic (in prep.).

We have contoured the major seismic horizons visible on the records and have tied these horizons back to wells on the Rankin Platform and nearby areas, via Gulf lines AU11, 12, 13 & 14 which run along the platform, and Gulf lines Au 15, 17, 19, 22 and 23, and Shell lines N212A, & N210A (see Pl. 1) which extend into the Exmouth Plateau area from the platform. The wells enabled us to assign ages to various reflectors, although these ages are unreliable across such a large area because the reflectors are unconformities in many places, because facies changes cause changes in reflector character, and because misidentifications across faults are always possible. However, the ages assigned are, we believe, useful aide-memoires for descriptive purposes.

26

Structural contour maps

A generalized structure contour map of the whole area (Fig. 5, 5B), and a more detailed map of the central area (Pl. 12), were prepared for Horizon F. Horizon F is an unconformity characterized by considerable displacements and marks the tops of numerous fault blocks. Many of the blocks are tilted landward. Well ties suggest that the unconformity extends from Late Triassic to earliest Late Jurassic time, and that the sediments below the unconformity probably range from Late Triassic to Early Jurassic.

The generalized map of Horizon F (Fig. 5, Pl. 5B) amalgamates swarms of related faults into 'fault-zones'. The large blocks bounded by fault-zones can be correlated with some confidence from one seismic line to another, whereas individual faults generally cannot.

Under the central part of the plateau is the broad northeasterly-trending Exmouth Plateau Arch (new name) with an average time-depth of 3 seconds. East of this is the broad parallel depression of the Kangaroo Syncline (new name), with an average time-depth of 3.5 seconds, east of which is the parallel uplift of the Rankin Platform. The F horizon falls steadily northwestward from the Exmouth Plateau Arch, but southwest of the arch a marginal ridge complicates the structure. This ridge extends some 200 km in a northwesterly direction and its culmination is as shallow as 2.12 seconds. The minimum time-depth between the ridge and the Exmouth Plateau Arch is more than 3 seconds. In the north the horst blocks of Wombat Plateau (culmination 2.56 seconds), Echidna Spur (culmination 3.83 seconds), and Emu Spur (culmination 2.65 seconds) dominate the structure. South of Wombat Plateau is a complex westerly-trending graben with time-depths as great as 6.3 seconds. Beneath Swan Canyon east of Emu Spur, time-depths commonly exceed 5 seconds.

Normal faulting is characteristic of the Exmouth Plateau, with the amplitude of faulting generally greatest nearest the outer margins. Many faults have a displacement of more than 0.2 seconds (ca. 200 m) and some of more than 1 second (ca. 1200 m). North-northeasterly faults are characteristic of the Exmouth Plateau Arch, but west of the arch the strike swings to northeasterly. Northwesterly faults prevail along the southwestern margin. Faulting is relatively unimportant in the Kangaroo Syncline, apart from a few major northeasterly-trending faults. In the north of the plateau the general northeasterly to northerly trends are complicated by the westerly trends of the graben south of Wallaby Plateau.

The Horizon F map of the central area (Pl. 12) clearly shows the highest area on the Exmouth Plateau Arch to be at about 19°30'S. The fault-bounded depression centred a few kilometres southwest of 114°00'E, 20°30'S is also very prominent. Another noteworthy feature is that the northeasterly trend, so apparent on most of this map, gives way southward to a weaker northwesterly trend.

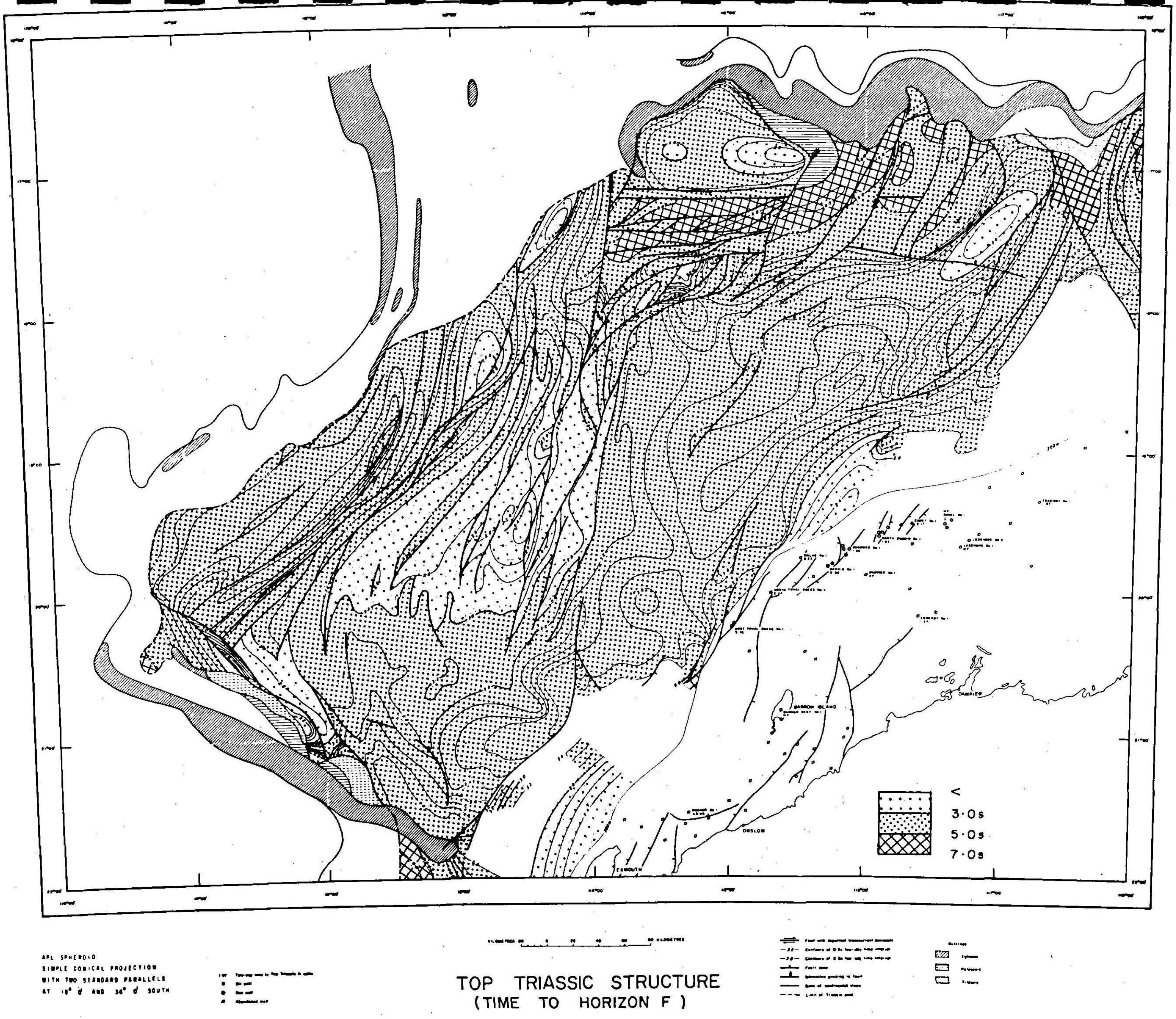
The Horizon D map of the central area (Pl. 11) shows the structure at the top of a markedly prograded deltaic sequence in the south, and of an equivalent shaly sequence in the north, which we believe corresponds to the Upper Jurassic/Neocomian Barrow Group. The prograded sequence has built northward, and the northern limit of the top-set beds is shown on the map. Horizon D reflects Horizon F but the structure is much more subdued. The culmination is 100 km south of the Horizon F culmination, and corresponds with the thickest part of the deltaic sequence. The depression in Horizon F near 114°E, 20°30'S has no expression in Horizon D. The abundant faulting of Horizon F has been largely obliterated by Jurassic sedimentation except in the northwest, where the Jurassic sequence is thin. Many of the northern horst blocks carry no Jurassic sediments at all (Pl. 11) and Horizon D is absent.

The Horizon C map of the central area (Pl. 10) is generally similar to the Horizon D map. Horizon C is a regional unconformity which corresponds approximately with the Senonian. Earlier Cretaceous sedimentation was thickest in the east, and the eastern depression centred on 114°20'E, 20°S (most apparent on the maps of Horizons F and D) is no longer recognizable. On several horst blocks in the west, older horizons merge with Horizon C because of lack of sediment. A rise in the southeast, which is not apparent at Horizon D, may possibly consist of slumped Senonian and Tertiary sediment. If it does not the area must have been low in the Cretaceous and have received thick sediment. The rise appears to be a northern extension of the Cape Range Anticline, and may have developed with it in the Tertiary.

The Horizon C map for the whole area (Fig. 6, Pl. 3B) shows the influence of Horizon F structure (Fig. 5, Pl. 5B), although Jurassic and Cretaceous sedimentation has heavily modified the older structure. Few of the faults apparent at Horizon F persist upward to Horizon C, except in the northeast. The Exmouth Plateau Arch (culmination at 1.8 seconds) bifurcates in the north into the northerly-trending Platypus Spur, and a northeasterly-trending ridge. The old Kangaroo Syncline is still apparent, but a more recent depression (maximum depth 3.4 seconds) underlying the northern Montebello Trough cuts across it. A relatively high block east of the

28

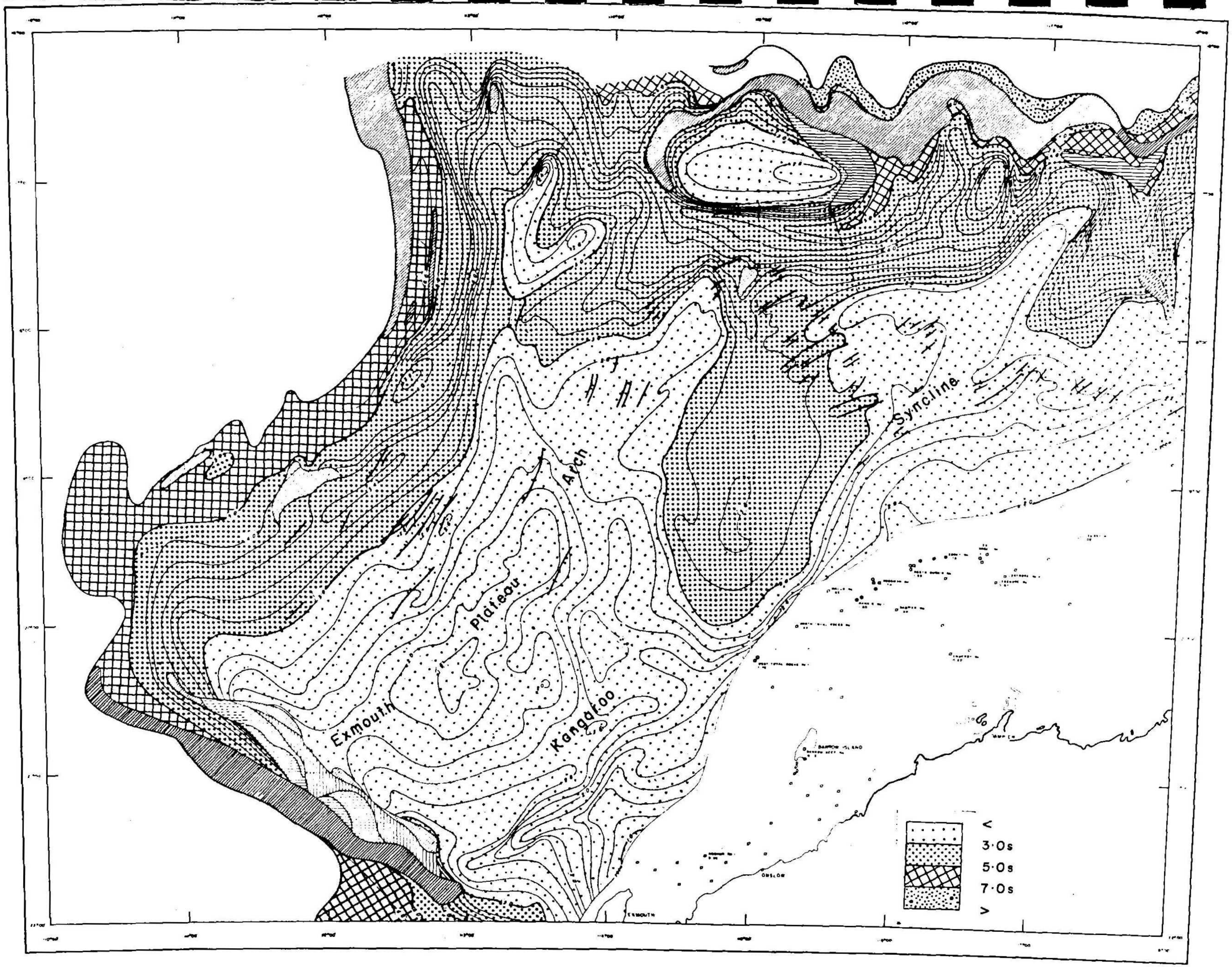
RECORD No. 1975/158



TOP TRIASSIC STRUCTURE
(TIME TO HORIZON F)

FIG. 5

WA/B8-71-2A

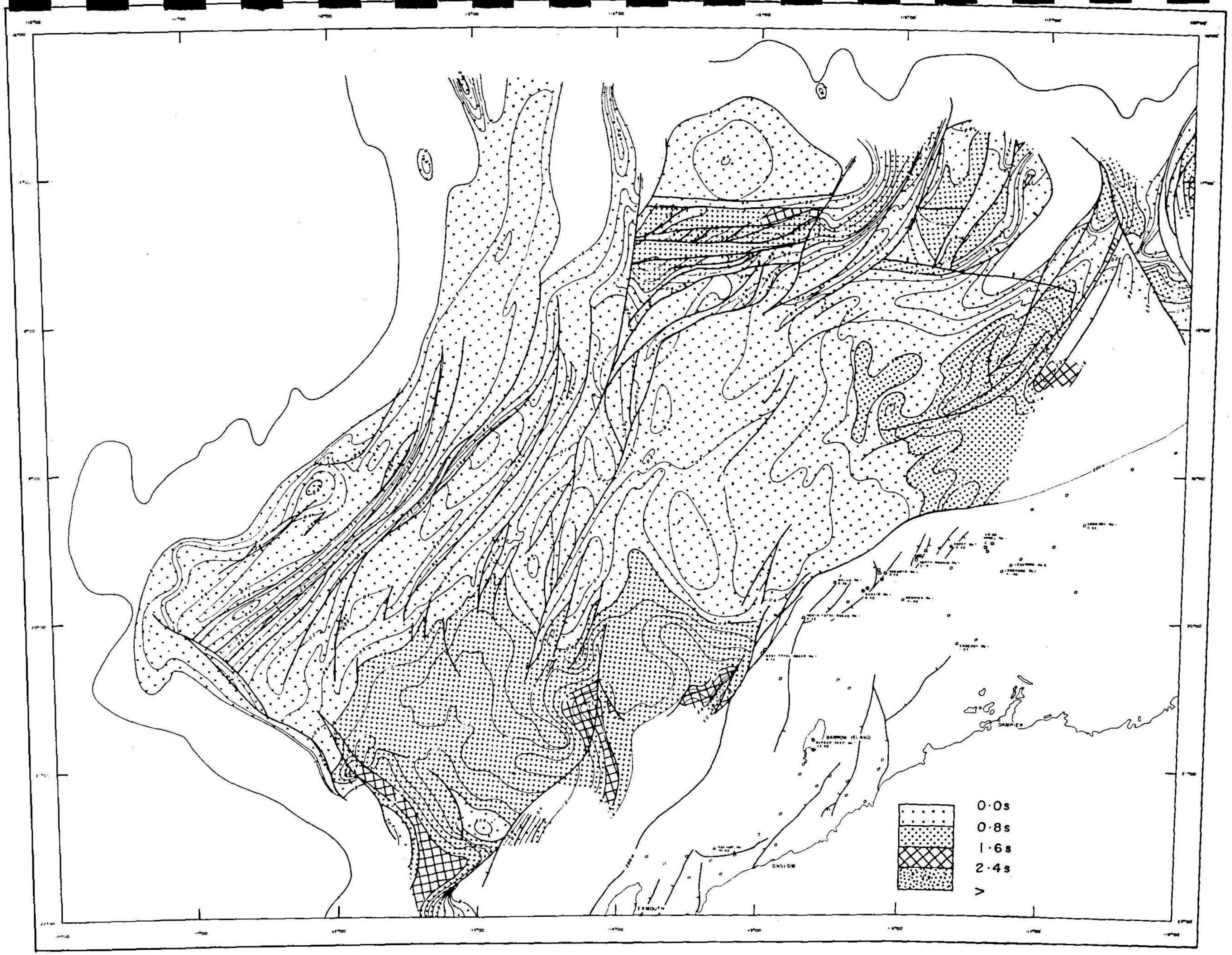


APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

SENONIAN STRUCTURE
(TIME TO HORIZON C)

FIG. 6

RECORD No 1975/158

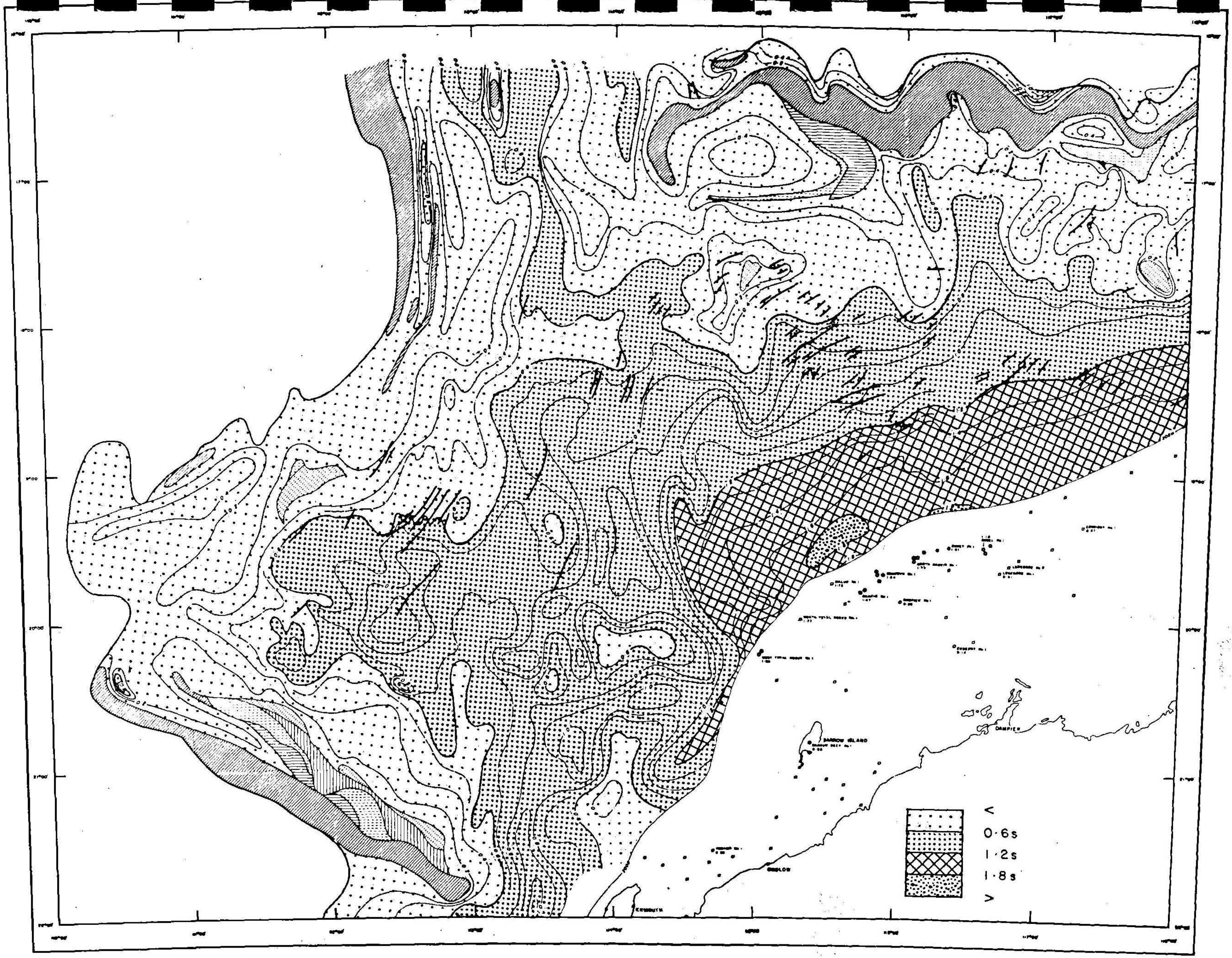


JURASSIC - SENONIAN TIME - THICKNESS
(TIME BETWEEN HORIZONS C AND F)

FIG. 7

WA/B8-72-1A

RECORD No 1975/158



APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

SENONIAN - CAINOZOIC TIME-THICKNESS
(TIME BETWEEN SEABED AND HORIZON C)

FIG. 8

WA/B8-69-1A

32

Montebello Trough (average depth 2.8 seconds) connects the Rankin Platform to the Emu and Echidna Spurs to the north, and the rise north of the Cape Range Anticline is a prominent feature. The ridge along the southwest margin of the plateau and the complex structures along the northern margin are subdued versions of those visible at the F Horizon.

The bathymetric map (Fig. 4, Pl. 2B), the last structural map, is very similar to the map of Horizon C. The Montebello Trough is narrower than its equivalent at Horizon C, and the high block north of the Rankin Platform is broader. The rise north of the Cape Range Anticline is no longer apparent. These changes came about because Cainozoic sedimentation was more rapid near the continent than farther offshore.

Thickness maps

A generalized map showing time-thicknesses between Horizon F and Horizon C is complementary to the Horizon F structural map. Another such map shows the time-thickness between Horizon C and the sea bed.

The Horizon F - Horizon C thickness map (Fig. 7, Pl. 6B) shows the time-thickness of Jurassic-Cenomanian sediment. The average thickness of this sequence is about 0.5 second with a general thinning away from the continent. Thicknesses of less than 0.4 second prevail along the western margin, presumably reflecting distance from the sediment source. Along the northern part of the Exmouth Plateau Arch, and on Platypus Spur, Wombat Plateau and Emu Spur, the sequence is also thin, suggesting that these features were far from source, and perhaps structurally high during deposition, or else were later uplifted and eroded. More than 1 second of section is present along other parts of the northern margin in a number of structures which are structurally low. Especially prominent is the graben south of Wombat Plateau.

Another area of thick Jurassic-Cenomanian sediment is the south, where more than 1 second and as much as 2.5 seconds of section is present. The various seismic sections show extensive northerly prograding in the area, and rapid thinning north of the prograded sequence. The thickening is interpreted as being caused by a thick Jurassic/Neocomian deltaic sequence correlative with that of Barrow Island. The general picture in Late Jurassic and Early Cretaceous time was of deltaic sediments building from the south across a fairly flat, fairly shallow shelf. The thickest sediments were deposited in the south,and in newly-formed structural depressions in the north.

33

The Horizon C - Seabed thickness map (Fig. 8, Pl. 4B), shows the time-thickness of Senonian to Cainozoic sediment (largely limestone). The average thickness of this sequence is about 0.6 second with, again, a general thinning away from the continent. Thicknesses of less than 0.4 second prevail along the outer margins of the plateau whereas along the continental margin thicknesses of greater than 1 second are common. Along the northern margin erosional and non-depositional areas are clearly related to the water depth. Above the extension of the Cape Range Anticline north of Exmouth sedimentation is thin because of Tertiary uplift. The distribution of thickness suggests that much sediment was derived from the vicinity of the present continental shelf, which in turn suggests that marls should be increasingly rare seaward.

There is little detailed correlation between the Senonian-Cainozoic and the Jurassic-Senonian thickness maps (Figs. 7 and 8). This is a reflection of the unconformities within the Late Cretaceous and Cainozoic, which are related to differences of tectonism in the two periods. The Senonian-Cainozoic thickness map is more closely related to the Senonian contour map (Fig. 7, Pl. 3B) than to the older maps. However a few features, notably the Montebello Trough, are much more strongly reflected structurally than as sediment thicknesses, suggesting that they developed during the Cainozoic.

STRUCTURE AND STRATIGRAPHY

In this chapter we discuss the relation of the seismic horizons and intervals to the geology of the Carnarvon and Canning Basins and outline the structure and stratigraphy of the Exmouth Plateau Arch, Kangaroo Syncline and the northern, western, and southern margins of the Exmouth Plateau. Depth and thickness estimates have been derived using the seismic velocities given in Appendix IV. The characteristics of the various seismic horizons are summarized in Table 2, and Table 1 relates them to the shelf stratigraphy.

Exmouth Plateau Arch and Kangaroo Syncline

Structurally, the Exmouth Plateau can be divided into a broad, north-northeasterly-trending arch and an adjacent syncline which follows the foot of the inner continental slope. The arch, the Exmouth Plateau Arch, occupies the western half of the Plateau. It culminates topographical at 113°E, 20°S. It is most simply defined by the Senonian (C) and Neocomian (D) seismic reflectors although it is quite evident at the Faulted 'Triassic' surface (F). The syncline, the Kangaroo Syncline, adjoins the eastern limb of the Arch but, in part, it underlies the present-day continental shelf break. Its axis diverges northwards from the axis of the Montebello Trough and at 18°S lies about 150 km farther east. It is most apparent at the 'Triassic' surface.

34

Table 2. Characteristics of seismic horizons

Horizon	Characteristics	Age	Comments
A1 (=Veevers' R2)*	Uppermost unconformity which separates an upper zone of semi-transparent flat beds from channel-fill (interval A1-A2) and from a lower zone of buckled beds (Plate 13A)	Tertiary unconformity: probably largely Oligocene (Table 1, Figure 9)	Can be traced throughout the area but has not been mapped for this report. Interval (seabed - A1) has prograded westward to form the continental shelf (Plate 13A, BMR 17/068)
A2	Unconformity marking the base of channels over most of the area. In some places A1 and A2 merge, and the combined reflector is called A	Tertiary unconformity: largely Early Eocene (Table 1, Figure 9)	Channels very apparent on BMR 17/074 (Pl. 13A) but also present farther south
B	Unconformity just within or near the base of the zone of contorted beds	Tertiary unconformity: probably largely Maastrichtian to Early Palaeocene (Table 1)	Probably occurs over most of the area but has not been mapped for this report. Horizon B has not been identified on the northern part of the Exmouth Plateau Arch. In some place Horizon B is a décollement surface along which slumping has occurred
C (=Veevers' R3)*	A strong reflector at the base of a thin well-stratified zone and overlying a semi-transparent zone. It is a mild angular unconformity in the southern area	Attributed to the base of the Santonian Toolonga Calcilutite and its equivalent. The unconformity spans the Turonian and Coniacian (Upper Cretaceous) and overlies the Aptian-Cenomanian Winning Group	Mapped throughout the area. Few major faults penetrate the horizon except in the northeastern Kangaroo Syncline. Compaction of the Jurassic and Cretaceous sediments has caused some draping of Horizon C
D	Marks the top of a zone of northerly prograding sediments in the southern part of the Plateau. It can be traced as a weak reflector elsewhere and usually marks the top of sediments which lie between upthrown fault-blocks	Top of Late Jurassic/Neocomian Barrow Group, according to well ties and structure of underlying sediments	Mapped through most of the area, but the reflector is weak and is identified somewhat uncertainly beyond the delta. Section (D-F) is absent from the top of may up-thrown fault-blocks in many places. Draping and compaction faults occur over several blocks

Table 2. Characteristics of seismic horizons (cont'd)

Horizon	Characteristics	Age	Comments
E	Strong reflector in northeastern Kangaroo Syncline only. Incorporated into the faulted blocks	Mid-Jurassic; possibly near top of the Dingo Claystone	Picked on BMR 17/074 only (Plate 13A)
F (=Veevers' R4)*	A strong reflector marking an angular unconformity near the top of the faulted blocks. Shows considerable displacements along faults which mostly terminate at, or just above, the horizon	Late Triassic to Early Jurassic unconformity - surface of Late Triassic to Early Jurassic Mungaroo Beds	Readily mapped. The faults become more intense towards the continental margin. The blocks are generally landward-tilted
G & H	Deep reflectors which broadly follow the structure of Horizon F (Plate 13B). Horizon G may be an angular unconformity	Palaeozoic: Horizon G possibly overlies Late Permian sediments	These horizons show the deep structure in parts of the Exmouth Plateau Arch, but are probably not correlatable from line to line. Both Horizons indicate a large faulted monocline beaneath the Plateau crest (Esso 2)
I	Envelope of numberous diffractions	Probably Precambrian basement equivalent to the Pilbara Block, dissected by Triassic to Lower Cretaceous intrusives and extrusives	Transitional basement associated with the rift-valley stage which preceded sea-floor spreading. Visible on seaward ends of seismic sections

* Horizons defined by Veevers et al., 1974

Horizons G and H (? Permian)

Seismic horizons G and H are the deepest reflectors that we can reliably identify. They are believed to lie within the Upper Palaeozoic section - Horizon G possibly corresponding to the top of the Permian; possibly equivalent to the Upper Permian Kennedy Group of the Carnarvon Basin (Thomas & Smith, 1974). Although reflectors G and H have been labelled on several sections they cannot be correlated with sufficient certainty for mapping purposes. Over most of the area Horizon G lies almost parallel to the overlying 'pre-Jurassic' (pre-Horizon F) beds, but on the crest of the Exmouth Plateau Arch and in the Dampier Sub-basin, southeast of the Rankin Platform, it is a marked angular unconformity (Pl. 13D, Esso 2; Pl. 13E, Gulf AU19/20).

Horizon G appears to be at maximum depth 20 km northeast of the Plateau crest, where it overlies the lower limb of a faulted monocline, 7000 m below sea level (overburden 6000 m)(Esso 2, Shell N213). It shallows westwards and probably crops out on the outer continental slope along the northwest and southwest margins of the Plateau (BMR 17/079). In the Kangaroo Syncline it lies at a similar depth, but shallows eastward to about 5000 m in the Dampier Sub-basin.

At the northern end of the Arch, along latitude 18°S, Horizon G culminates in the core of a faulted anticline which forms the foundation of Platypus Spur (Pl. 13A, BMR 17/074). It lies 3000 m below sea level (over-burden 1600 m) and the anticline has an east-west closure of about 1000 m. The section (F-G) thins by 750 m from the limbs to the crest of the anticline but it is uncertain if the thinning is depositional or erosional.

The faulted monocline beneath the Plateau crest has a maximum displacement of 2000 m between its limbs. Depositional thinning has occurred across the structure but most of the thinning within the section (F-G) is due to extensive erosion in the Late Triassic or Early Jurassic, preceding block-faulting.

Interval (F-G): Triassic section

The section corresponding with the interval (F-G) is probably equivalent to the deltaic and fluvial Mungaroo Beds of the Carnarvon Basin. In the Onslow area the Mungaroo Beds consist of fine to coarse-grained sand-stone with interbedded claystone and are Middle to Late Triassic. On the Rankin Platform the Beds are coarser-grained and more porous and extend into the Early Jurassic. These beds seem to have built northward and possibly westward as time progressed, and may have been deposited during the Early

Jurassic on the Exmouth Plateau. This suggests that if a Lower Jurassic sequence is present, part of it probably lies beneath the F unconformity.

On the Plateau the lithology of the Mungaroo Beds or their equivalent is likely to be very variable as the seismic velocities determined from sonobuoy records range from 2800 to 4000 m/s (Appendix IV, Table B).

All major hydrocarbon accumulations on the Rankin Platform have been found in the Mungaroo Beds, where they are trapped in horst blocks formed before deposition of the Middle or Upper Jurassic.

Horizon F (Late Triassic - Early Jurassic)

Horizon F is the most prominant unconformity in the Exmouth Plateau area. It is readily identified on the Exmouth Plateau Arch where considerable angularity occurs between beds within faulted blocks and the overlying ponded sediments. Passing eastward across the eastern limb of the Arch and into the Kangaroo Syncline, it becomes less angular and lies at progressively greater depths within the blocks.

In tying to the wells on the Rankin Platform via the Gulf lines (Pl. 13E, Gulf AU19/20: Pl. 13F, Gulf AU12/13/13B/14) we find that the horizon lies within or on top of the uppermost Triassic section. As the Jurassic was absent in wells on the Rankin Platform the unconformity cannot be directly dated with any precision. Erosion could have occurred at any time from latest Triassic to earliest Cretaceous. However, a Late Triassic to Early Jurassic age seems preferable as this was a period of instability farther east, within the Canning Basin, and because the Jurassic was a period of sustained subsidence and rapid sedimentation within the Carnarvon Basin (Thomas & Smith, 1974). Further, in Cossigny No. 1 well, an unconformity separates Middle to Upper Triassic Mungaroo Beds from the Lower to Middle Jurassic Enderby Formation. On the Exmouth Plateau Arch the unconformity is overlain by wedges of ponded sediments which are probably Early to Middle Jurassic and these are overlain in turn by a prograded sequence which is undoubtedly the Upper Jurassic/ Neocomian Barrow Group. In summary, the Horizon F unconformity on the Exmouth Plateau may generally fall within the time span Late Triassic to Early Jurassic but in places separates the beds which range from Late Triassic to as young as ? Late Cretaceous.

Horizon F broadly parallels the present-day seabed (Pls 2 and 5A); its amplitude on the time maps and seismic sections is exaggerated by velocity effects of overlying layers, particularly the water layer. The horizon is incorporated within the Exmouth Plateau Arch in which it has an overall closure of 900 m and a culmination about 3100 below sea level. The 'post-Triassic' (post-Horizon F) section is 2100 m thick forms a crest on the prolongation underlying Platypus Spur at a depth of 2400 m and beneath a 'post-Triassic' section of 1000 m.

On and west of the Arch, the block-faulting, which affects the horizon but only rarely extends into the overlying section, intensifies westwards forming numerous elongate blocks with north-northeasterly trends and progressively large landward dips (Pl. 13A, BMR 17/068). Along the northern margin of the Plateau the horizon falls away northward into a series of half-grabens along easterly-trending faults which appear to be of a similar or slightly greater age (Pl. 13B, BMR 18/008). The steep southwestern margin is formed by intense southeasterly-trending faults of younger age, which cause Palaeozoic and Triassic strata to crop out on the continental slope.

Within the Kangaroo Syncline the horizon lies at an average depth of about 4000 m and is overlain by 2800 m of 'post-Triassic' section. It dips gently eastward from Arch to Syncline although most of the faults continue to be downthrown westwards. Locally, as an Esso 2 (Pl. 13D) the Syncline appears to be intensely faulted. In the northern part of the Kangaroo Syncline (Pl. 13A, BMR 17/074; Pl. 13E, Gulf AU19/20) the axis lies beneath the present-day progradations of the continental shelf and upper continental slope. Horizon F lies deep within the faulted blocks which in this area were formed or rejuvenated in the Late Jurassic/Neocomian (Horizon D) and even into the Late Cretaceous.

The broad folding which occurs throughout the section pre-Horizon A indicates that, apart from a local Permian high in the area of Platypus Spur, folding of the Exmouth Plateau Arch and probably the Kangaroo Syncline took place in Late Tertiary. Some of the movement was evidently taken up by rejuvenation of the old block-faults but these rarely show up as clean fractures in the Upper Cretaceous and Cainozoic.

Interval (D-F): Jurassic/Neocomian Section

We consider that the interval (D-F) corresponds with a section of Middle Jurassic to Neocomian age. The Jurassic is absent in wells on the Rankin Platform although Upper Jurassic was intersected in Egret No. 1 well (Pl. 13F, Gulf AU12/13/13B/14), and Jurassic sediments, comprising the shallow marine Dingo Claystone and the deltaic to fluvial Barrow Group (Fig. 9), are present in the Dampier, Barrow, and Exmouth Sub-basins. On the Exmouth Plateau any Lower Jurassic sequence probably lies beneath the F unconformity. The Middle Jurassic probably consists largely of ponded sediments on the downthrown side of the 'Triassic' fault-blocks, but we also expect it to be found within post-Triassic basins (see below) and at the bottom of the thick sections on the southern part of the Exmouth Plateau Arch and Kangaroo Syncline (Fig. 7, Pl. 63). The Neocomian beds contain a prograded section which is undoubtedly the deltaic Barrow Group. The deltaic section is confined to the southern half of the area (Time-thickness map (Fig. 7, Pl. 63); its northern limit being shown on the 'Jurassic' map of the central area (Pl. 11).

The 'Jurassic' is thickest and shallowest beneath the Plateau crest where the uplifted top-set beds of the delta cap a section which is 2100 m thick (Pl. 13B, BMR 18/069). Slightly north of the delta front the section is 1400 m thick but it progressively thins northward to virtually zero across the easterly-trending 'Triassic' fault-blocks at 18°S. Locally, thick 'Jurassic' occurs on downthrown blocks and as a lens, 1500 m thick, across the Arch at 20°S (Pl. 13A, BMR 17/068). Within the Kangaroo Syncline the 'Jurassic' appears to thicken northward from a few hundred metres west of the Tryal Rocks area (BMR 17/068) to 1700 m northwest of North Rankin No. 1 (Pl. 13A, BMR 17/074). In the northern area a mid-Jurassic horizon (E) has been identified but not mapped.

Compaction of Jurassic sediments has led to thinning and minor faulting over the downthrown side of many fault-blocks. Rejuvenated 'Triassic' faults cut the Jurassic section in several places. Within the Kangaroo Syncline deposition of Jurassic sediments appears to have preceded the main episode of block-faulting.

In areas where the 'Jurassic' section is thickest, Horizon D follows the broad structure of the Exmouth Plateau Arch but Horizon F is a flatter surface, which must originally have been basin-shaped or have been depressed under the load of Jurassic sediments (BMR 17/068, Pl. 13A; BMR 18/069, Pl. 13B).

The 'Jurassic' sediments appear to be an extension of those within the Carnarvon Basin. On the Arch, the lowermost part of the section probably consists of ponded sandstone and siltstone derived locally by rapid erosion of uplifted fault-blocks, together with finer-grained material from the south. These rocks are lateral equivalents of the Dingo Claystone. The relatively coarse-grained sediments of the Upper Jurassic/Neocomian delta are expected to give way northwards to a more argillaceous section. The portion of the

Arch immediately north of the delta front, and the northern part of the Kangaroo Syncline were probably marginal basins which received sediments during most of the Jurassic.

Sediments within the delta are expected to contain a high proportion of porous permeable sandstones which could be good reservoir rocks. Lateral migration of hydrocarbons from the Jurassic and Lower Cretaceous mudstones to the north could have taken place, and elevation of the delta front in the Late Tertiary would have aided this process. Beneath the Plateau crest irregularities occur within the top-set beds, which could be caused by a cap-reef, although slumping cannot be ruled out.

Horizon D (Neocomian)

On the southern part of the Arch, Horizon D is an unconformity overlying the Upper Jurassic/Neocomian Barrow Group (Pl. 13B, BMR 18/069). Beyond the delta front the horizon descends abruptly and degenerates into a weak reflector which is commonly within an acoustically semi-transparent zone. Although it cannot be followed with certainty, it appears to overlie wedges of ponded sediments lying in the low sides of the faulted 'Triassic' blocks and a lens of poorly bedded sediments on the southern part of the Arch (Pl. 13A, BMR 17/068). In the Kangaroo Syncline the unconformity surface lies approximately parallel to the present-day sea-bed and is incorporated into the faulted blocks.

On the top-set beds of the delta, Horizon D is at its shallowest depth, 1700 m below sea level, beneath an overburden of about 800 m. Between the delta front and the northern margin of the Plateau it forms two terraces (Pl. 13B, BMR 18/069); 2200 m below sea level from the delta front to 19°S, and 2700 m below sea level from 19°S to 18°S. Farther north, it occurs in the half-graben south of Wombat Plateau. The horizon dips southward from the delta top-sets and is 2300 m below sea level along the southwestern margin of the Plateau. Northward of the delta front most of the variation in depth is due to different depositional regimes of the Upper Jurassic/Neocomian section; however, to its south the broad arching of Horizon D, caused by Late Tertiary movements, results in about 600 m relative uplift.

In the southern part of the Kangaroo Syncline the horizon again represents the top of a deltaic section which has completely filled the older 'Triassic' trough (Pl. 13D, Esso 2; Pls. 11 and 12 for structural maps). It is about 2700 m below sea level, beneath an overburden of 1600 m. West of the Rankin area the horizon tops a thin 'Jurassic' section beyond the delta front, at a depth of 3200 m below sea level (Pl. 13A, BMR 17/068). Along the foot of the inner continental slope, north of Egret No. 1 well, Horizon D appears to be unrelated to the 'Triassic' horizon in the Syncline. It is at a maximum depth of 2900 m (overburden 1200 m) beneath the Montebello Trough and at 2600 m (overburden 1200 m) over the axis of the Syncline. It is intersected by faults of Late Cretaceous and Middle Tertiary age (Pl. 13A, 17/074).

Interval (C-D): Aptian - Senonian

The interval (C-D) lies within a zone which is acoustically semi-transparent, and is believed to correspond with the mid-Cretaceous (Aptian to Cenomanian) Winning Group of the Carnarvon Basin. The section apparently comes to outcrop on the western and southwestern margins of the Plateau.

Over most of the Exmouth Plateau Arch the Section (C-D) is 200 to 300 m thick with progressive thinning to about 100 m along the northern margin of the Plateau (Pl. 13E, Gulf AU19/20). However, west and northwest of Barrow Island the section is considerably thicker. On Gulf AU15 (20°30'S) it increases from 350 m thick south of the Plateau crest to 1500 m beneath the continental slope. The relief visible on the surface of the Jurassic/Neocomian delta is not reflected on the surface of the Albian/Senonian sequence, which is locally thick beyond the delta front (Pl. 13B, BMR 18/069). The overall arching of the interval appears to be due to Late Tertiary warping. It is locally thin on the western limb of the Arch and on the northern end of Gulf AU19/20 where it rests directly on elevated 'top-Triassic'. Thinning also occurs across Platypus Spur which appears to have been a structural high throughout the depositional history of the area. In areas where the older horizons have considerable structural relief the section shows signs of compaction and associated compaction faults.

On the eastern limb of the Arch, between 19° and 20°S, the section (C-D) apparently forms a lens about 1800 m thick and 100 km wide. Varying dips on beds within the upper part of this lens are similar to those on a transverse section through a prograded sequence which may have built upwards and outwards to form a delta tongue. However, the picking of seismic horizon C is in doubt in this area. Although the pick as shown on BMR 17/068 (Pl. 13A) has been made by following a continuous reflector around the network, it seems to be out of character, and it is possible that the top of the Winning Group lies beneath the lens and correlates with a band of reflectors 0.2 to 0.3 second (250-375 m) above Horizon A. If this is so, the lens of sediments must lie within the Senonian to Early Tertiary.

42

North of Egret No. 1 well the interval is 100 to 200 m thick and is incorporated into the faulted blocks (Pl. 13A, BMR 17/074). On some sections it appears to outcrop against the overlying Senonian at 116°45'E.

Northwest of Barrow Island correlation of the interval (C-D) with the Winning Group is substantiated by the thickness determined from the seismic sections, which agrees exactly with the 1500 m of Winning Group discussed by Thomas & Smith (1974). The Winning Group is shallow marine and is predominantly a sequence of claystone and siltstone which were deposited from Aptian to Cenomanian time, following a transgression in the Aptain. The basal unit is an arenite (Birdrong Formation) which is generally 15 to 30 m thick. On the Exmouth Plateau Arch its counterpart is probably locally derived arenite on the flanks of faulted blocks which were protruding through the Jurassic in Aptian time. It is overlain by a shale and siltstone sequence (Muderong Shale and Gearle Siltstone) which on Barrow Island incorporates the Windalia Sand Member. The Windalia Sand has high porosity but low permeability and is the main producer in the Barrow Island oilfield. Thinning of the Winning Group towards the northern and western margins of the Exmouth Plateau is apparently related to distance from the source, suggesting that the Group contains little pelagic sediment.

An age of formation of the southwestern edge of the Exmouth Plateau can be deduced from a study of BMR lines 17/052 and 17/054 just beyond the southern edge of our maps. Across the southern margin of the Exmouth Sub-basin, a complete sequence of Jurassic to Silurian formations subcrop progressively under the Winning Group, and near Pendock No. 1 well (113°20'10"E, 23°16'52"S) Winning Group lies directly on steeply dipping Carboniferous rocks (Geary, 1970, Fig. 8). Using BMR lines 17/052 and 17/054 Veevers & Johnstone (1974, figs. 11 and 12) have correlated the Winning Group in Pendock No. 1 with a sequence of Aptian/Albian black pelites from DSDP263 (Veevers, Heirtzler, et al., 1973) which lies at 5065 m water depth on the Cuvier Abyssal Plain (Fig. 2). The correlation is based on a distinctive lithology, shallow marine biota, and continuity of the Winning Group inferred from a composite of the two seismic sections. Although DSDP263 did not reach basement, examination of the seismic section BMR 17/052 indicates that the Winning Group probably lies directly on an igneous layer which extends beneath the continental slope. Veevers & Johnstone (1974) have proposed that the igneous layer represents true oceanic basement but this seems improbable. Falvey (1974) has argued concerning the initiation of spreading that 'there is no evidence that any true oceanic tholeiites are extruded prior to actual breakup' and when breakup ultimately occurs the ridge is at bathyal depth. The situation west of Pendock may be similar to that proposed by Whiteman (1968) for formation of the Red Sea depression. In the Red Sea extensive subsidence of continental basement has occurred and parts of it are now deeper than 2000 m; however, the generation of oceanic crust is minimal. We consider it more likely that DSDP263 overlies continental basement which has been metamorphosed and injected by dykes of intermediate composition or that it overlies a layer of trap basalt interbedded with clastic sediments, which were laid down during the early stages of block-faulting (Beck, 1972). Continental basement at or near the level of the abyssal plain has also been proposed in the Great Australian Bight (Willcox, 1974; Boeuf & Doust, 1975). Apart from a major fault on the outer shelf, about 75km west of Pendock, basement appears to increase in depth continuously across the continental slope; however, in detail, it seems probable that it falls ocean-ward along numerous small faults. This tends to be confirmed by digital processing of BMR 17/054.

In summary, south of the Exmouth Plateau, the Winning Group was probably deposited over continental basement which shortly afterwards underwent metamorphism and dyke injection during formation of an incipient rift zone. The basement was continuous with that beneath the Exmouth Plateau. A fault formed along the southwestern edge, and a few northerly-trending block-faults formed beneath the present-day continental shelf and slope. In post-Cenomanian time, most probably during the Turonian and Coniacian, which are periods of hiatus in the Carnarvon Basin Exmouth Plateau region, the area subsided. By the time carbonate deposition commenced in the Santonian (Veevers & Johnstone, 1974, Fig. 4) the Winning Group west of Pendock was at bathyal depth. During the Santonian to Maastrichtian the Toolonga Calcilutite and Miria Marl were laid down on the continental shelf and redeposited as a turbidite sequence on the 'Cuvier Abyssal Plain'. Between the Santonian and the present the margin subsided to its present depth.

Horizon C (Santonian)

Seismic Horizon C lies near the base of a band of strong reflectors which generally separate an overlying zone of well stratified but contorted beds from an underlying semi-transparent zone. On most of the Exmouth Plateau Arch the horizon parallels the underlying beds but in a few place, most notably over the Jurassic/Neocomian delta, it is a mild angular unconformity. Ties to wells on the Rankin Platform (Pl. 13F, Gulf AU12/13/13B/14) indicate that it lies near the base of Tertiary or within the uppermost Cretaceous section. It is equivalent to seismic horizon R3 mapped by Veevers et al. (1974). We consider that the band of reflectors incorporating Horizon C is probably caused by alternating shale and carbonate at the bottom of a thick carbonate sequence and is a lateral equivalent of the Santonian Toolonga Calcilutite.

Horizon C is incorporated into the Exmouth Plateau Arch and culminates above the top-set beds of the delta beneath the Plateau crest at a depth of 1700 m (overburden 700 m). An east-west section across the southern part of the Arch (Pl. 13A, BMR 17/068) shows a secondary culmination near the outer edge of the Plateau at 2700 m (overburden 600 m). On the eastern limb of the Arch it overlies a lens of sediments which may be Santonian to Lower Tertiary (see discussion under 'Interval (C-D)'). Across the northern part of the Arch (Pl. 13A, BMR 17/074) its culmination lies beneath the Platypus Spur at 2100 m depth (overburden 700 m). The horizon extends north-northeastwards from its culmination above the delta to 19°30'S, at little more than 1700 m below sea level, then falls away to form a terrace between 19°00'S and the northern edge of the Plateau at 2500 m below sea level. Horizon C has also been mapped in the half-graben south of Wombat Plateau and on the continental rise.

Beneath the Montebello Trough the horizon forms a broad syncline with its axis 3000 m below sea level (overburden 1600 m) on BMR 17/068 and 2100 m below sea level (overburden 900 m) on BMR 17/074. It becomes progressively shallower beneath the continental slope and shelf, and is 400 m below sea level in Enderby No. 1 off the southeastern end of Gulf AU19/20 (Pl. 13E).

Horizon C is largely unaffected by faulting, although draping and minor compaction faults occur on the western limb of the Arch where section (C-D) is thin. In the northern part of the Kangaroo Syncline (BMR 17/074) several faults extend to this horizon and upwards into the Santonian and Tertiary.

<u>Horizons A1, A2 & B and the Senonian - Cainozoic interval</u>

The interval overlying Horizon C was laid down after the Turonian to Coniacian hiatus (Veevers & Johnstone, 1974) and is correlated with the section overlying the unconformity at the base of the Toolonga Calcilutite or its equivalent (Fig. 9). In the Tryal Rocks area the section ranges from Santonian to Recent, but its age may vary somewhat in other areas as the Toolonga is time-transgressive.

Prominant unconformities have been picked on sections crossing the Exmouth Plateau Arch and Kangaroo Syncline, but others are probably obscured by the complex of channels, slumping, and synsedimentary faults within the section. They have not been followed in detail on all sections, and at this stage maps have not been prepared. Across the southern part of the Arch (Pl. 13A, BMR 17/068; Pl. 13D, Esso 2) two unconformities have been picked: the lowermost, Horizon B, lies within a zone of contorted beds or in some places near the base of the zone, and follows the gross structure of the Arch;

the uppermost, Horizon A1, separates the contorted beds from parallel beds above. In a few places an intermediate unconformity, A2, marks the bed of erosion channels, and A1 lies on top of the channel-fill. Elsewhere, A1 and A2 seem to be coincident. Across the northern part of the Arch (Pl. 13A, BMR 17/074) Horizons A1 and A2 are clearly present, but Horizon B has not been identified. In this area A1 and A2 bifurcate beneath the Montebello Trough, and A2 can be traced towards the shelf beneath progressively thicker overburden while A1 cannot be traced far in this direction.

On the Exmouth Plateau Arch Horizons A1/A2 generally lie 200 to 400 m below the sea-bed. However, the section (seabed-A) thins across Platypus Spur and Horizon A1 probably crops out on its western flank. Over the Kangaroo Syncline, on BMR 17/068, Horizon A1 lies about 1900 m below sea level (overburden 600 m). It becomes progressively shallower beneath the shelf where it underlies several sequences of prograded beds (Pl. 13E, Gulf AU19/20). On the southern part of the Arch Horizon B is generally about 500 m below sea-bed and culminates 1400 m below sea level on the crest of the Arch. Some draping occurs on the western limb of the Arch.

The age of the unconformities defined by the Horizons A1, A2, and B remains speculative as accurate well ties cannot be made, owing to abrupt changes in thickness of the Cainozoic across the outer continental shelf and continental slope. However, in the Tryal Rocks area (Quilty, 1974) there are three unconformities (Fig. 9) to which we may equate those beneath the Exmouth Plateau:-

Horizon A1	Eocene to early Miocene	Giralia Calcarenite to Cape Range Group
Horizon A2	Late Paleocene to Eocene	Cardabia Group to Giralia Calcarenite
Horizon B	Maastrichtian to late Paleocene	Miria Marl to Cardabia Group

The interval (B-C) is a uniform 300 to 400 m thick over most of the Arch but is only 200 m thick over the thick lens of sediment on the eastern limb. (The age of this lens is discussed under 'Interval (C-D)'.) The section shows slight compaction and draping over the western limb. It was probably deposited as a fairly uniform layer across a flat or gently dipping surface before the Late Tertiary arching of the area. If it is equivalent to the Toolonga Calcilutite and Miria Marl, as we propose, it probably represents

Table 3. Sedimentation rates: Senonian-Cainozoic

Intervals considered (time breaks excluded)	Sedimentation rate (m/million years)						
	DSDP Hole No 260	Exmouth Plateau Arch	Kangaroo Syncline	Barrow Deep No.1	West Tryal Rocks No.1	Rankin No. 1	Legendre No. 1
Late Miocene - Recent		Low	Low	0	210	150	120
Early Miocene - Recent (seabed-Horizon A_1)		10	50	10	60	45	25
Late Palaeocene - Late Eocene (Horizon A_1 - Horizon B)		30	30	5	70	110	40
Santonian - Maastrichtian (Horizon B - Horizon C)		20	20	7	10	10	20
Santonian - Recent	?	15	18	10	40	45	40
Santonian - Recent (time breaks included)	2	10	12	3	30	30	15
Location	Deep Sea *	Exmouth Plateau		Barrow Sub-basin +	Rankin Platform +		Dampier Sub-basin ⊕

* Calculated from Veevers, Heirtzler et al. (1973)

\+ Calculated from Table 1, Figures 9 and 10

⊕ Calculated from Table 1, Figure 9, well completion report a carbonate sequence laid down over 17 m.y., at an average rate of 20 m per million years (Table 3).

The interval (A-B) is far more variable in thickness than the intervals above and below it. In general it is thin over the crest of the Arch and comparatively thick on the lower limbs. It is characterized by contorted beds and minor faults, particularly below areas where the gradient is steep (Pl. 13B, 18/069). These are obviously caused by large-scale, but probably low-displacement gravity slumping of the semi-consolidated carbonates during the Paleocene to Miocene. We believe that these slides accompanied the formation of the present-day Arch. The contorted beds which straddle the crest on BMR 17/068 are probably caused by local dislocations owing to a zone of tension at the Arch crest. It is also possible that the lens of sediments on the eastern limb lies within the post-Senonian and, if so, it may have resulted from a major gravity slide, involving several hundred metres of sediments. The 'glide surface' for most of the movement lies close to Horizon B. We consider that the interval (A-B) is composed of Palaeocene and Eocene carbonates which are equivalent to the deep marine Cardabia Group and Giralia Calcarenite in the West Tryal Rocks area (Fig. 9). Assuming that the interval includes a late Paleocene/Eocene hiatus as at Tryal Rocks, the average depositional rate on the Arch was about 30 m per million years.

The Paleocene to Miocene seems to have been a period of accelerated downwarping of the present-day Exmouth Plateau and outer continental shelf. The Exmouth Plateau was arched upwards relative to its margins, and this may have been related to a zone of weakness beneath the eastern limb of the Kangaroo Syncline, comparable to that beneath the outer margin. This is consistent with the intense block-faulting extending into the Tertiary, which occurs on the eastern limb of the Syncline (BMR 17/074).

The early Miocene to Recent section, interval (seabed-A), consists of a thick westward-prograding carbonate sequence forming the outer continental shelf. The prograding appears to have taken place in stages, at least three of which are evident on Gulf AU19/20. Beyond the upper continental slope the section is considerably thinner and its well-bedded character gives way to a semi-transparent one, which may reflect the sparseness of shallow-water carbonate and an increased pelagic carbonate content. The sediment accumulation rates on the Arch, Syncline, and outer continental shelf are calculated at 10, 50, and 80 m per million years, respectively.

48

FIG. 9

Approximate Age (Million years)	Tryal Rocks Area (Southwest): Name	Interval	Environment	Legendre Area (Northeast): Name	Interval	Environment	Seismic Reflector
	Unnamed	Pliocene-Recent	Shelf and Slope Marine	Unnamed	Pliocene-Recent	Shelf Marine	
10	Trealla Limestone equivalent	M. Miocene	Shelf Marine	Trealla Limestone	E-M. Miocene	Shelf Marine	T_1
							T_2
20	Cape Range Group equiv.	E. Miocene	Shelf Marine				
30							
40	Giralia Calcarenite equivalent	Eocene	Deep Marine	Giralia Calcarenite	L. Eocene	Shelf Marine	E
50				Cardabia Group equivalent	L. Paleocene – M. Eocene	Shelf Marine	T_4
	Cardabia Group	L. Paleocene	Deep Marine				
60							X
70	Miria Marl equivalent	Campanian-Maastrichtian	Shelf Marine	Miria Marl	Campanian-Maastrichtian	Shelf Marine	D
80	Toolonga Calcilutite equivalent	Santonian	Shelf Marine	Toolonga Calcilutite	Santonian	Shelf Marine	
90–100	Windalia Radiolarite, Gearle Siltstone equivalent	Albian-Coniacian	Shelf Marine	Winning Group	Neocomian-Turonian	Shallow Marine	F
110–120	Muderong Shale	L. Neocomian-Aptian	Shallow Marine				Y
130	Barrow Group	Neocomian	Deltaic to Fluvial	Barrow Group	Kimmeridgian – Neocomian	Deltaic to Fluvial	H
150	Dingo Claystone equivalent	Jurassic	Shallow Marine to Deltaic	Dampier Formation	Oxfordian — Kimmeridgian	Fluvial to Deltaic	J_C
160–170				Legendre Formation	M. Jurassic	Shallow Marine	J
180–190				Enderby Formation	E.-M. Jurassic	Fluvial to Deltaic	T
200	Mungaroo Beds	M.-L. Triassic	Fluvial to Deltaic	Mungaroo Beds	M.-L. Triassic	Fluvial to Deltaic	

Notes: True time breaks known for Cainozoic sequence only
Lithological key on Figure 3

49

GENERALIZED STRATIGRAPHY
TRYAL ROCKS - LEGENDRE AREA

RECORD No 1975/158 E50/B8-41A

Assuming that the Exmouth Plateau has remained in bathyal depths since the Maastrichtian, the three unconformities could have been produced by slumping, currents, internal waves, or solution of carbonate. There are similar unconformities on the Northwest Shelf (e.g. Quilty, 1974), but little has been published about their mode of origin. As most of the carbonates there were deposited in shallow water (Fig. 9), most of the unconformities were probably produced by normal shelf processes such as tidal currents and wave action, or possibly even by subaerial erosion. However in the Tryal Rocks area, Quilty (op. cit.) shows an early Eocene unconformity separating deep-water carbonates, and this unconformity probably was formed in a similar manner to those on the Exmouth Plateau.

The deep-sea drilling program has shown that unconformities exist in the abyssal sediments of all the oceans, and Rona (1973) suggested that two hiatuses were synchronous in all the principal ocean basins: early Paleocene and Oligocene. Davies et al. (1975) have shown that these hiatuses are widespread in the eastern Indian Ocean, and suggested that they were caused by vigorous deep-ocean currents, and by solution of carbonate below the carbonate compensation depth (3000 - 4000 m). They suggested that both unconformities could be related to climatic deterioration and Antarctic glaciation, which might have increased the amount of Antarctic Bottom Water entering the Wharton Basin. However deep-sea drilling near Antarctica (Hayes, Frakes et al., 1973) has provided no evidence of Palaeocene cooling, and has shown that extensive glaciation began on the Antarctic continent only in the early Miocene, and hence cannot have caused the Oligocene unconformity.

Kennett, Burns et al. (1972) pointed out that the interpretation of magnetic anomaly patterns, which show that Australia began to separate from Antarctica in the early Eocene, has important implications for palaeocurrent patterns. They suggested that until the late Oligocene the circum-polar current flowed around Australia, but thereafter followed its present route between Australia and Antarctica. If this were the case, widespread erosion and non-deposition of pre-Miocene deep-sea sediments in the Wharton Basin could be expected, as occurs at the present day in the area of the Antarctica current (Watkins & Kennett, 1973).

Neither the continental shelf nor the deep-ocean situation can have been completely applicable in the bathyal depths of Exmouth Plateau during the Cainozoic. Slumping occurred within the Cainozoic sequence, but was restricted both areally and stratigraphically. Only in the formation of the Horizon B unconformity, which lies toward the base of a contorted sequence in some areas, can it have played an important role.

50

Currents may have played a major part in forming the unconformities. Both the pre-Miocene circum-Antarctic current hypothesized by Kennett, Burns et al. (op. cit.), and the present northerly-flowing West Australian Current could have caused widespread erosion in periods when oceanic circulation speeded up because of deteriorating climatic conditions. Tidal currents may also have been important. Surface currents of more than 150 cm/s occur on the Northwest Shelf 100 km offshore during spring tides, and maximum rates of around 50 cm/s are common in the area (Jones, 1973). Thus, tidal currents may well have caused erosion at depths of several hundred metres in the Exmouth Plateau region.

Internal waves commonly occur at the depth of the thermocline, which in this area probably lies between 100 and 200 m deep. Such waves can cause erosion, but too little is known about the oceanography of the Exmouth Plateau area to be able to predict their position, magnitude, or effect with any degree of certainty today, let alone in the past.

Solution of carbonate is normally restricted to the deep oceans, but Worsley (1971, 1974) suggested that the worldwide Maastrichtian-Early Paleocene unconformity was caused by solution, even at shelf depths. He hypothesized that the great plankton bloom which produced widespread Maastrichtian chalk decreased atmospheric carbon dioxide, leading to worldwide cooling. The cooling increased the solubility of carbon dioxide and hence decreased the level of carbonate saturation in the ocean. At the same time the amount of $CaCO_3$ entering the ocean declined steadily because the base level of erosion on the continents was being approached. Eventually even shallow waters become undersaturated in $CaCO_3$ (i.e. the carbonate compensation level reached the surface) and widespread solution occurred, causing the worldwide hiatus. Conditions were then unfavourable to the plankton, carbon dioxide was released to the atmosphere, and conditions returned to normal. This mechanism would be capable of producing an hiatus of perhaps 1 million years, but not the longer unconformities which we see.

In summary, currents appear to have been the major cause of erosion on the Exmouth Plateau during the Cainozoic, and normal ocean currents probably predominated over tidal currents. The present sea bottom shows evidence of erosion and deposition, but the canyons of the area appear to be dormant (Falvey & Veevers, 1974).

Northwestern and Southwestern Margins

The northwestern margin of the Exmouth Plateau generally consists of one or more terraces formed by the oceanward collapse of major blocks of pre-Triassic and Early Jurassic sediments. The collapse, relative to the Plateau crest, probably took place from the time of formation of the block-faults (rift-valley stage of continental breakup (Falvey, 1974)) onwards. It probably reached a peak shortly after continental separation and the generation of oceanic crust during the Callovian (Upper Jurassic) (Veevers & Heirtzler, 1974), and generally preceded overall subsidence of the Plateau region. Gradual shallowing of crystalline basement towards the margin is observed on most seismic sections and is confirmed by the presence of relatively high frequency magnetic anomalies (Pl. 13A and 14). Basement crops out on the lower continental slope in several areas. It is probably of a transitional composition, consisting of Pilbara Block metamorphic rocks, and Triassic and Jurassic igneous rocks associated with the early stages of continental breakup. In some places (Pl. 13A, BMR 17/068) an outer terrace is composed of elongate igneous bodies subparallel to the margin, which retain ponded Cretaceous sediments and are overlain by Cainozoic pelagic sediments. The abyssal plain and presumably tholeiitic oceanic basement lies slightly west of this terrace.

The southwestern margin is composed of upturned and outcropping pre-Cretaceous strata overlying a south-southeasterly-trending belt of igneous rocks up to 50 km wide. The sedimentary rocks are extensively block-faulted over a distance of only 30 or 40 km and several of the faults are downthrown to the northeast. On Esso Line 3A a lava flow appears to overlie the Triassic strata. These structures are consistent with the hypothesis that the southwestern margin is formed by a fault which became active around Turonian or Coniacian time (Fig. 13). Igneous activity along the fault buttressed the Plateau margin and continued subsidence of the Plateau led to the formation of northeasterly-downthrown faults. Rapid collapse of the continental margin south of the fault carried portions of the Aptian-Cenomanian Winning Group to bathyal depth by the Santonian as explained on Page 28. From then on the Cuvier Abyssal Plain subsided to its present depth.

Northern Margin

The area adjacent to the northern margin of the Exmouth Plateau (northward of latitude 18°S) is made up of a complex of horsts and grabens, which results from relative movements along north-northeasterly and easterly-striking faults. Several small sub-plateaux which occur on the horst blocks

52

(Pl. 13A, BMR 17/079), in water depths of 1600 to 2300 m were once part of Exmouth Plateau. The largest, the Wombat Plateau (Fig. 4), covers an area of about 3500 km^2. Identification of reflectors in the northern area is impeded by lack of continuity across the grabens which separate the sub-plateaux, and between the sub-plateaux and the Exmouth Plateau proper. However, the F and D horizons can be traced with moderate confidence onto the Echidna and Emu Spurs and elsewhere all horizons can be picked by character correlation. The pattern of faults shown on the Triassic Structure and Jurassic-Senonian Thickness maps (Pls. 5B and 6B, Figs. 5 and 7) is highly interpretative and schematic as there are too few lines in the area for the orientation of faults to be plotted accurately. The interpretation shown, which is one of several possibilities, is based on the age identification of the seismic horizons and the fault pattern deduced from the magnetic anomaly map (Pl. 7).

In general, the northern margin of the Plateau is downwarped along a highly faulted hinge zone, but in detail it consists of numerous blocks downfaulted northward or northwestward into a series of half-grabens(Pl. 13B, BMR 18/008; Pl. 13E, Gulf AU19/20; also Shell N209 & N210). The sub-plateaux which separate the half-grabens from the Argo Abyssal Plain, are probably largely composed of westerly-dipping Palaeozoic strata (pre-Horizon F) beneath nearly horizontal Mesozoic and Cainozoic strata and have been buttressed against collapse by igneous intrusions along their northern edges.

The deepest reflector identified on the seismic sections is equated with the Late Permian reflector - Horizon G. It is a highly faulted horizon 4000 m below sea level (overburden 1800 m) beneath Echidna Spur, and 6600 m below sea level (overburden 3600 m) beneath the adjacent graben. On the eastern side of Wombat Plateau, pre-Horizon G beds are folded into a northerly-trending anticline which crops out on the intensely faulted eastern escarpment (Pl. 13A, BMR 17/079). Other pre-Horizon G outcrops probably occur above the abyssal plain on the northern edge of Wombat Plateau but none can be recognized on BMR 18/008.

On the northern margin and in the half-grabens, the Late Triassic/ Early Jurassic unconformity, Horizon F, again outlines the surface of faulted blocks; however, within the sub-plateaux few faults are observed. In the 'Wombat half-graben' the Jurassic-Neocomian interval (D-F) is 1200 m thicker than on Wombat Plateau and must have been deposited in a structural low. However, the Aptian-Cenomanian interval (C-D) shows little variation in thickness between the sub-plateau and half-graben, although it seems to have been eroded off the northern edge of the Exmouth Plateau.

Until the Cenomanian, the area of the 'Wombat half-graben' was probably a slight structural low overlying an old Palaeozoic trough which may have been an extension of the Fitzroy Trough (Fig. 1). Extensive block-faulting developed in the Late Triassic and Jurassic during the rift-valley stage which preceded formation of oceanic basement to the west and north of the Exmouth Plateau area. The complexity of the faults, and their change of strike from north-northeast to east-northeast in the half-graben are probably related to the old structures which lay perpendicular to the incipient spreading centre. The Wombat Plateau seems to have resisted most of the block-faulting which curves around its southern and eastern side. From the Santonian onwards the northern area underwent gradual subsidence but because the sub-plateaux were buttressed by igneous bodies a group of half-grabens developed, which have a flat-bedded fill of Cainozoic sediments - probably a mixture of locally derived clastics from the high blocks, carbonates, and carbonate turbidites. The main faults in the half-graben may have been active until recent time.

On Emu and Echidna Spurs the Jurassic and Triassic appear to underlie a wave cut platform upon which post-Miocene carbonates have been deposited. The Early Tertiary may have been stripped from this area during uplift in the Eocene and early Miocene when the Exmouth Plateau Arch was forming.

Our seismic interpretation (see Fig. 5 and Pl. 5B) indicates that there are three stages of faulting in the northern area. However, Stages I and II may not be discrete since they could be different trends within the same stage.

Stage I. These faults lie along the axis of the 'Wombat half-graben' and affect the pre-Jurassic section.

Stage II. The predominant north-northeasterly-trending faults on the Exmouth Plateau affect the section ranging from pre-Jurassic to pre-Neocomian and are attributed to the 'rift-valley stage' which preceded continental break-up.

Stage III. These faults trend northeast to east, forming the hinge-line along the northern edge of the Exmouth Plateau and the active northern edge of the 'Wombat half-graben'. They affect the section from Santonian to Recent but are probably reactivated Palaeozoic or Stage II faults.

The easterly trend shown by Stage I faults, or by Stage II faults curving around the Wombat Plateau, is probably controlled by the deep structure. A well defined magnetic anomaly trough (for discussion see 'Gravity and magnetic anomalies') corresponds with the 'Wombat half-graben' and extends eastwards along the northern margin of the Exmouth Plateau. Although it is partly caused by elevated basement blocks to the north giving rise to large dipolar anomalies, its linearity suggests that there may also be a contribution from a deep-seated structural trough. This could be a westerly extension of the Fitzroy Trough in the northern Canning Basin. North-south offsets of the magnetic anomaly trough on meridians 115°30', 116°30' and 117°00'E indicate that there may be a fourth stage of faulting which has a transcurrent component.

GEOLOGICAL HISTORY

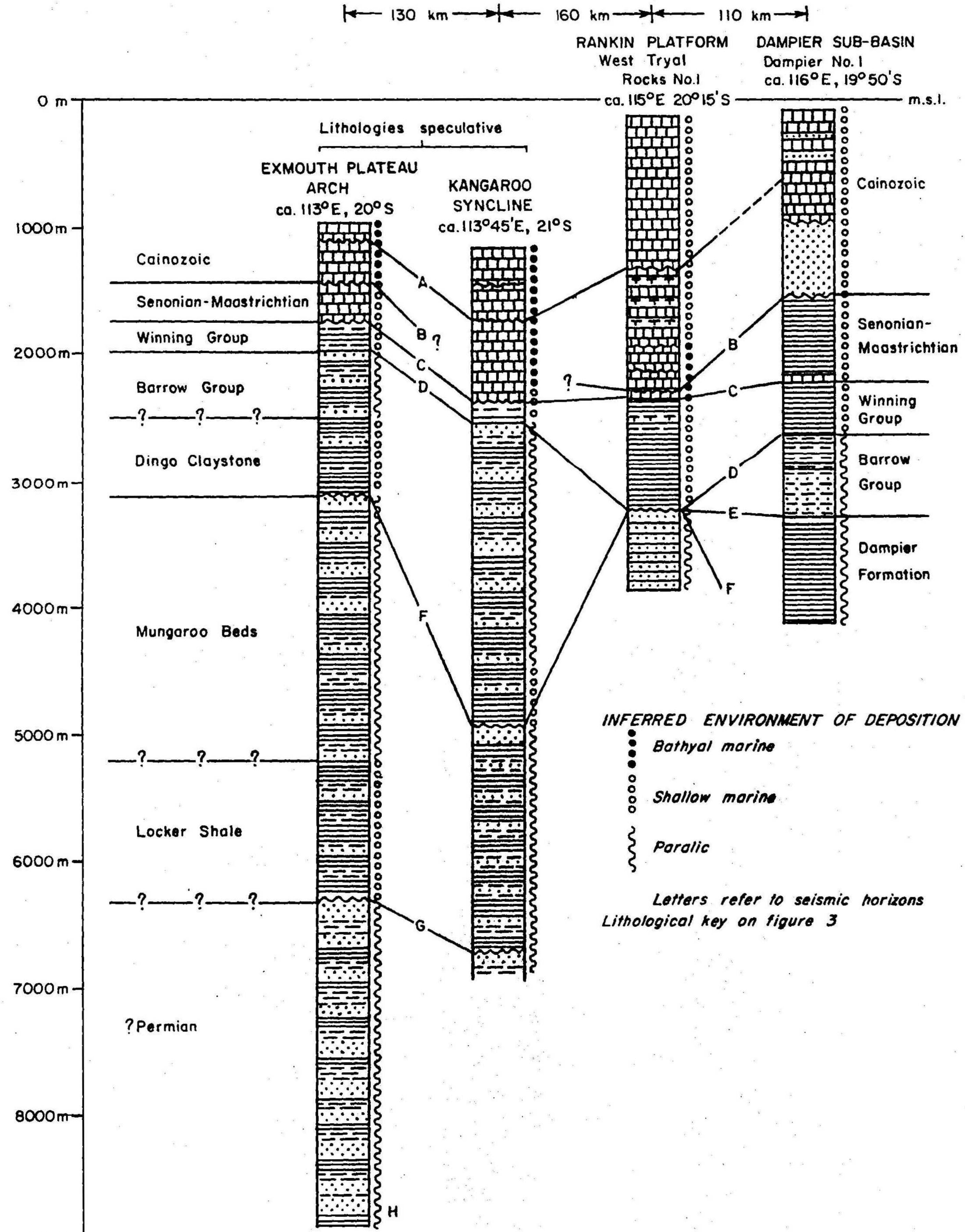
A generalized geological history of the Exmouth Plateau region, from Permian to Recent time, can be deduced from this study. The pre-Permian history is unknown but is probably similar to that revealed by drill holes and outcrops in the Canning, Carnarvon, and Perth Basins (Challinor, 1970; Thomas & Smith, 1974; Geary, 1970). The structural evolution is outlined schematically in Figures 11, 12, & 13, and the geological history is summarized in Table 4.

Precambrian

By analogy with the outcropping Pilbara, Kimberley, and Yilgarn Blocks the Precambrian basement underlying the Exmouth Plateau area is probably composed of Archaean igneous and metamorphic rocks, in places overlain by Proterozoic sedimentary and volcanic rocks.

Palaeozoic (pre-Permian)

Cambrian and Ordovician shelf deposition occurred across most of the Canning Basin and probably across the northern half of the Exmouth Plateau area, in contrast to non-marine deposition in the Perth and Carnarvon Basins (Veevers, 1971). In the Silurian, relative uplift of the Precambrian hinterland provided an abundant source of sand which accumulated as a thick sequence of redbeds west of the Darling Fault and in a trough in the southern Canning Basin. As planation of the hinterland progressed the supply of terrigenous material decreased and by the Early Devonian an arm of the Tethyan Ocean had entered the Canning and northern Carnarvon Basins, providing quiescent conditions that were favourable for deposition of shallow-marine evaporites. During the Late Devonian and Early Carboniferous shallow-marine and deltaic



56

CORRELATIONS BETWEEN DAMPIER SUB-BASIN
AND EXMOUTH PLATEAU ARCH

sediments were deposited in the northern Carnarvon Basin and the Fitzroy Trough, and finer-grained deeper-marine sediments were probably deposited on the Exmouth Plateau.

Permian

Uplift along the eastern margin of the Carnarvon Basin towards the end of the Carboniferous and cold, moist climatic conditions led to the formation of glaciers in the Precambrian highlands. In the Early Permian marine shelf sediments containing ice-rafted erratics were deposited in the trough of the Carnarvon Basin, and glaciofluvial and shallow-marine sands blanketed the southern Canning Basin and the Fitzroy Trough. By the Middle and Late Permian conditions had stablized and shallow-marine sands and silts were being deposited over the northern Carnarvon Basin and probably also in the Exmouth Plateau region. In the southern Carnarvon Basin continental sandstones were laid down, ending a long period of non-deposition. The Late Permian may have been a period of mild folding on the Exmouth Plateau which led to the formation of a north-northeasterly-trending monocline beneath the Exmouth Plateau Arch and an anticline beneath Wombat Plateau. However, these structures may not have formed until the Late Triassic. The total thickness of Palaeozoic sediments deposited in the Exmouth Plateau area exceeds 5000 m.

Triassic - Early Jurassic

Deposition of shallow-marine sediments continued uninterrupted from Permian to Triassic in the Carnarvon and Canning Basins (Locker Shale). During the Middle Triassic conditions became progressively less marine leading to widespread deposition of the deltaic to fluvial Mungaroo Beds. The equivalents of these beds probably underlie the main unconformity (Horizon F) on the Exmouth Plateau. The combined thickness of the Locker Shale and Mungaroo Beds is as much as 3700 m (Fig. 10).

In Triassic to Early Jurassic times the area was subjected to tension due to thermally induced arching and rift-valley formation along the north-western margin, which preceded the continental break-up of Gondwanaland. Associated fault movements initiated the Exmouth-Barrow-Dampier downwarp, which may be an aborted rift, and the Kangaroo Syncline. The Rankin Platform remained as an erosional high between them. Uplift and erosion also took place in the southern Canning and southern Carnarvon Basins. The Exmouth Plateau area was extensively faulted and sliced into numerous north-northeasterly-trending blocks. On the northern margin the faults tended to bend around the old rigid structures and to follow a zone of weakness along a possible extension of the Fitzroy Trough. In the central Exmouth Plateau areathe block-faulting was accompanied by uplift and erosion but on the western margin, where the faulting was most intense, blocks with high relief appear to have been rapidly buried by younger sediments.

Jurassic and Early Cretaceous (Neocomian)

The Jurassic was a period of continued tectonic activity and downwarping in the northern Carnarvon Basin and Exmouth Plateau areas. Alkaline volcanism probably accompanied the collapse of major fault-blocks around the margin. During the Early and Middle Jurassic locally derived sediment was ponded on the downthrown side of the faulted blocks, particularly in the western part of the area reducing most of the topographic relief. Draping, differential compaction, and minor rejuvenation of the Triassic faults occurred throughout the Jurassic. Subsidence of the basins on either side of the Rankin Platform continued, and slight downwarping in the area of the Exmouth Plateau crest and the 'Wombat half-graben' led to a marine incursion and deposition of thick prodeltaic muds (Dingo Claystone). During the Late Jurassic, deltaic sands prograding from the south and east advanced across the southern half of the Exmouth Plateau and the Canning and northern Carnarvon Basins (Barrow Group). By the late Neocomian the delta had attained a maximum thickness about 50 km southwest of the Plateau crest, where the combined thickness of Dingo Claystone and Barrow Group was about 2000 m.

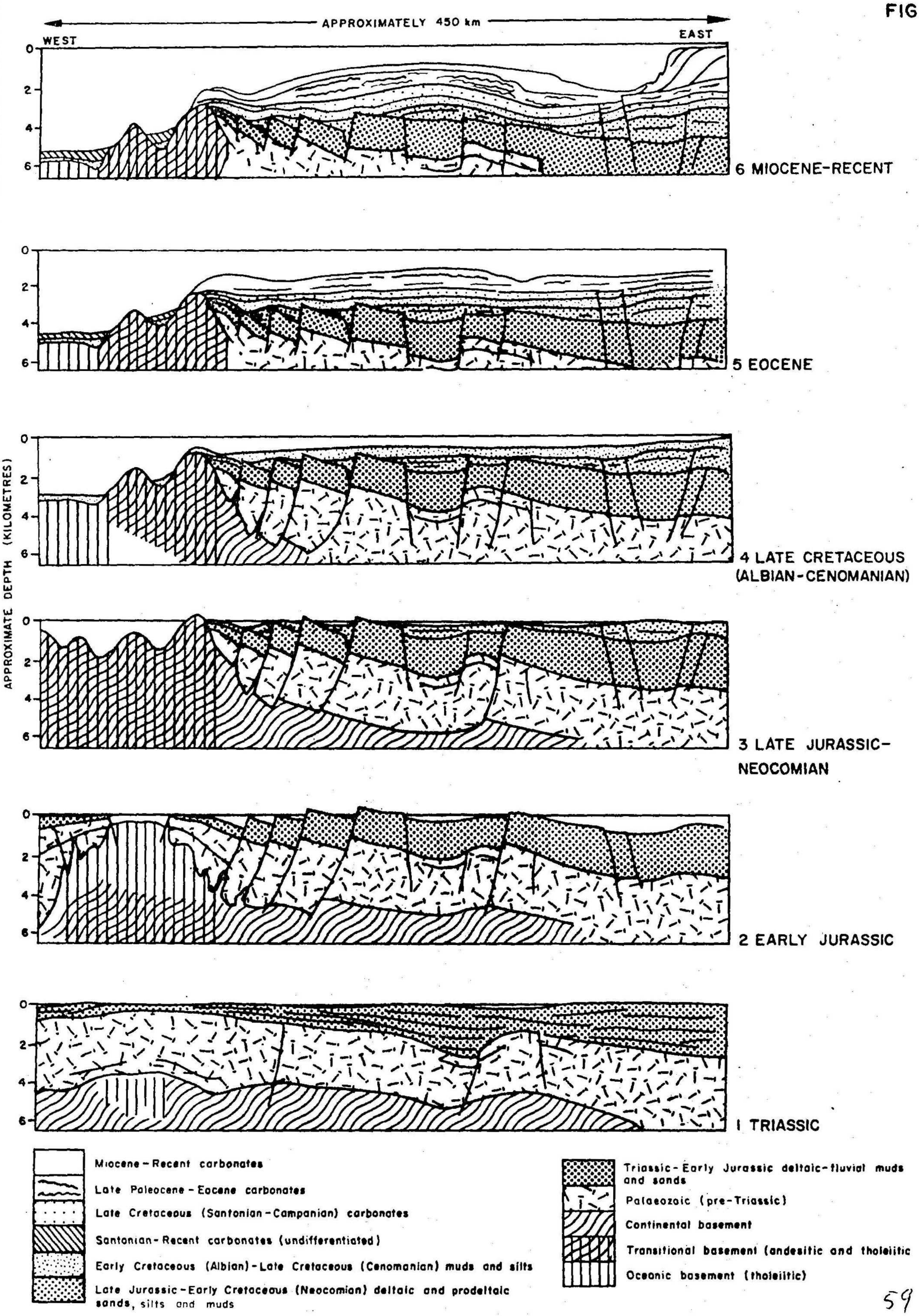
The splitting off of western Gondwanaland and generation of oceanic crust commenced off the western and northern margins of the Exmouth Plateau in the Callovian (lowermost Late Jurassic). North-northeasterly-striking spreading ridges formed west of the Exmouth Plateau and Northwest Shelf, and were linked by a latitudinal transform fault associated with igneous intrusions along the northern edge of the sub-plateaux and spurs (Fig. 13).

Early Cretaceous (Aptian) - Late Cretaceous (Cenomanian)

In the Late Jurassic a further incipient spreading ridge may have formed against the continental margin southwest of the Exmouth Plateau (Fig. 13). Uplift and block-faulting of the offshore Pilbara Block resulted in termination of Jurassic deposition and an angular basal Cretaceous overstep. Near Pendock No. 1 Well the earliest Cretaceous sediments (Aptian Winning Group) were deposited across northward-dipping Silurian to Jurassic strata and, farther west, across transitional crystalline basement.

In the Canning Basin and Exmouth Plateau area, Cretaceous (Aptian Winning Group) followed Jurassic (Neocomian Barrow Group) sedimentation without angular discordance. From the Aptian to Cenomanian, marine muds and silts

FIG. 11

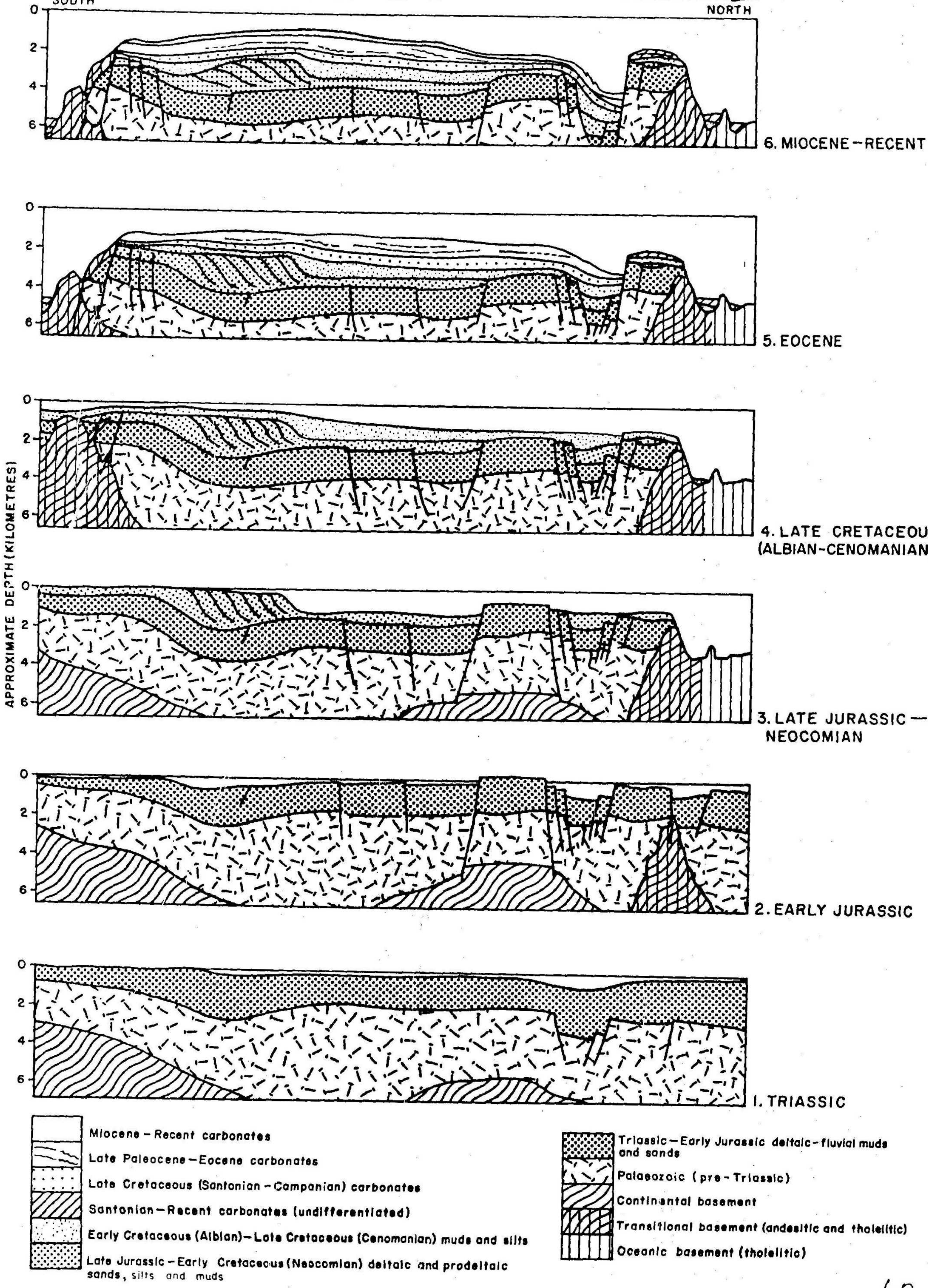


SCHEMATIC EAST-WEST CROSS-SECTIONS SHOWING STRUCTURAL EVOLUTION OF THE EXMOUTH PLATEAU AREA

RECORD No 1975/158

WA/B8-100A

FIG. 12



SCHEMATIC NORTH-SOUTH CROSS-SECTIONS SHOWING STRUCTURAL EVOLUTION OF THE EXMOUTH PLATEAU AREA

(Winning Group) blanketed the area, obscuring the topographic relief of the delta and any elevated Triassic blocks, including the Rankin Platform. The sediments have an average thickness of 200 m but reach a maximum thickness of 1500 m just beyond the delta front, northwest of Barrow Island. Throughout this period the continental shelf and Plateau were tilted slightly oceanwards and subsidence and readjustment of blocks continued, particularly along the outer edge of the Plateau. The only area which underwent intense tectonic activity was in the Kangaroo Syncline north of the Rankin Platform, where late-stage block-faulting seems to have occurred.

Late Cretaceous (Turonian - Coniacian)

Except for some muds deposited in the Dampier Sub-basin the period from Turonian to Coniacian is an hiatus throughout the region. The possible commencement of sea-floor spreading on the northeasterly-trending ridge west of Pendock No. 1 well (113°20'10"E, 23°16'52"S) could have led to the formation of a northwesterly-trending transform fault along the southwest margin of the Exmouth Plateau (Fig. 13). Alternatively, the southwest margin could have formed by collapse along normal faults. Igneous activity along the marginal faults buttressed the Exmouth Plateau, but on the southwest side of the faults the Australian continental margin subsided rapidly and the Winning Group was probably at bathyal depth by the Santonian.

Late Cretaceous (Santonian and Campanian)

When sedimentation recommenced in the Senonian there was a distinct change from detrital to carbonate deposition. This may have resulted from changes in oceanic circulation as spreading progressed, leading to increased organic productivity; or from the northward movement of Australia into a sufficiently warm latitude; or from a worldwide increase in carbonate productivity and sedimentation. During the Santonian and Campanian, carbonates were laid down on a westerly-tilted platform which extended from the continental shelf of the Carnarvon Basin to a few hundred metres water depth on the Exmouth Plateau (Toolonga Calcilutite and Miria Marl). The most rapid deposition took place on the Exmouth Plateau Arch and Kangaroo Syncline areas (Table 3). At this time, however, uplift and westerly tilting of the Rowley Shelf (offshore Canning Basin) resulted in extensive erosion of the Upper Cretaceous and earlier sediments. In the area north of the Exmouth Plateau reactivation of older faults led to rapid subsidence of the half-grabens relative to the sub-plateaux and spurs. The Emu Spur possibly remained elevated at this stage and underwent erosion along with the Rowley Shelf.

Latest Cretaceous (Maastrichtian) - late Paleocene

The Maastrichtian to late Paleocene was a period of non-deposition throughout the Exmouth Plateau region, possibly caused by changes in oceanic circulation. Fairly rapid subsidence of the Exmouth Plateau area probably occurred at about this time.

Late Paleocene - Eocene

Deep-water carbonate oozes were deposited across the area in the late Paleocene and Eocene. The Exmouth Plateau Arch started to form at about this time largely by subsidence of the western margin and Kangaroo Syncline areas relative to the central area. Block-faulting occurred in the north-eastern Kangaroo Syncline, and in the area north of the Plateau existing faults remained active. These movements led to formation of an inverted basin in Jurassic sediments on the crest of the Arch, and caused uplift of the Jurassic/Neocomian delta. The upturning of strata along the southwestern margin of the Plateau probably resulted from its relative stability with respect to the rest. Large-scale, but generally low-displacement gravity slumping of the semi-consolidated carbonates occurred throughout this period.

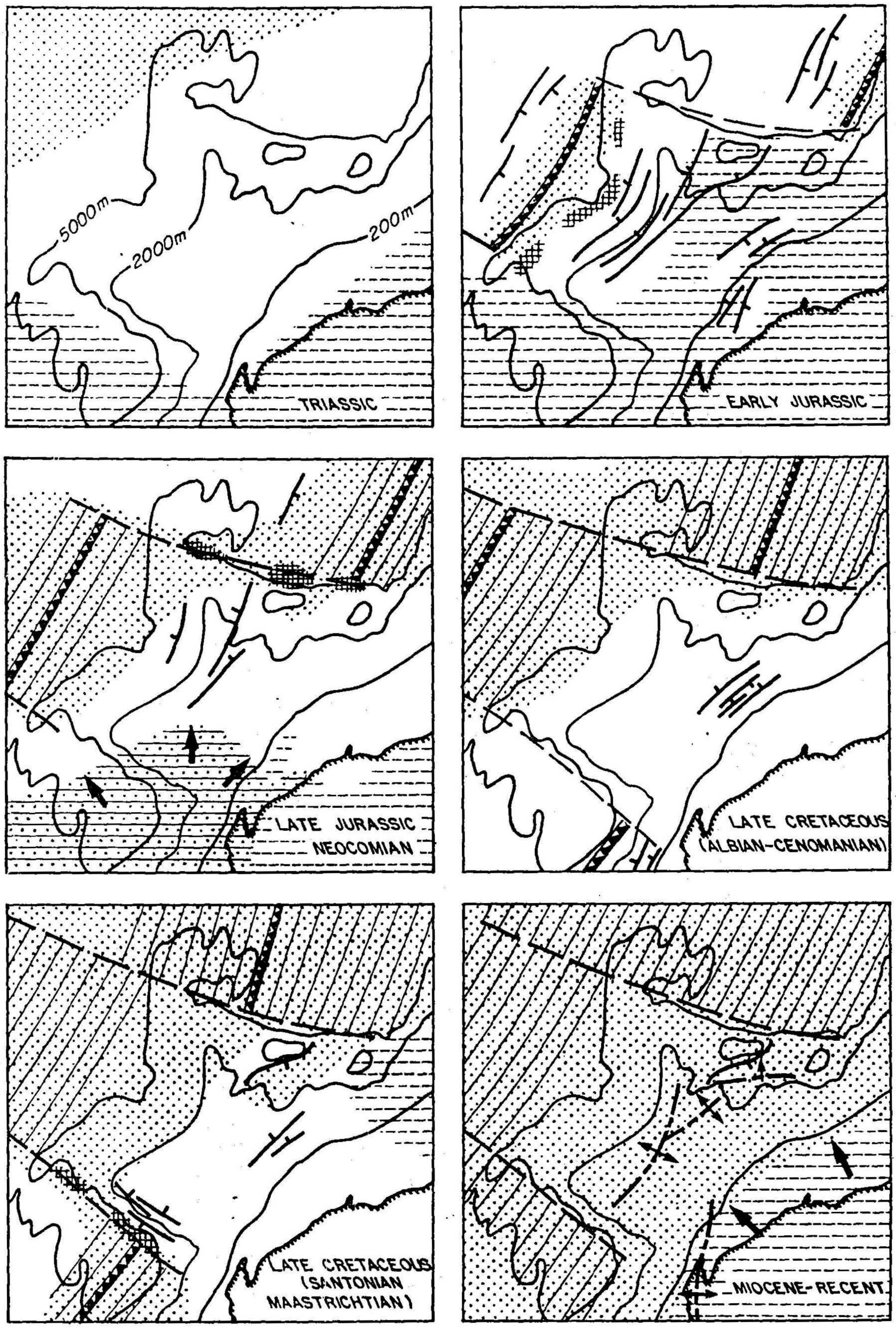
Eocene - early Miocene

This was an hiatus throughout most of the area, possibly caused by changes in circulation. By early Miocene time the present-day features of the Exmouth Plateau and the Cape Range Anticline had fully formed. Challinor (1970) has proposed that Oligocene sediments were stripped from the Rowley Shelf as a result of these movements but that forset-bedded Oligocene clastic carbonates occur in the outer shelf zone. Several structures of this age on the Northwest Shelf have been related to the Ramelauen Orogeny in Timor (Audley - Charles, 1968), and isostatic adjustments of the unstable margin of the continent during the collision of the Australian Plate with the Indonesian Arc.

Early Miocene - Recent

A thick sequence of Miocene and Pliocene carbonate clastic sediment prograded oceanwards and extended the shelf edge to its present position. The westward advance of the Shelf edge appears to have taken place in at least three bursts. On the Exmouth Plateau itself the Miocene to Recent deposition was largely of pelagic carbonate. By this time the Emu Spur had subsided sufficiently for carbonate to be deposited on an eroded Triassic sequence. Modern-day currents along the Montebello Trough have removed considerable quantities of this sediment and the late Miocene to Recent sediment accumulation rate is consequently very slow(Table 3). An average thickness of 700 m of Santonian to Recent carbonate sediments was deposited on the Exmouth Plateau.

FIG. 13



Spreading ridge with oceanic crust
Transform fault
Hinge
Fault
Anticline
Progradation

Deep marine
Shallow marine
Deltaic
Igneous intrusion associated with breakup
Fluviatile

—200m— Present-day isobath

63

TECTONIC AND PALAEOGEOGRAPHICAL RECONSTRUCTIONS OF THE EXMOUTH PLATEAU

RECORD No 1975/158

WA/B8-99A

Throughout this period the Exmouth Plateau and the continental shelf have probably continued their gradual subsidence under an increasing sediment load.

Table 4. Summary geological history of the Exmouth Plateau

Precambrian	Archaean igneous and metamorphic rocks. Proterozoic sedimentary and volcanic rocks
Palaeozoic (Pre-Permian)	Shelf sea with some shallow-marine evaporites. Terrigenous redbeds in S.
Permian	Glaciofluvial and shallow-marine sands and silts deposited.
Triassic - E. Jurassic	Shallow-marine regressing to fluvial. NNE-trending block-faulting. Formation of Kangaroo Syncline.
Jurassic & E. Cretaceous (Neocomian)	Relief of fault-blocks lowered. Delta in S. Sea-floor spreading, and transcurrent fault along N boundary.
E. Cretaceous (Aptian) - L. Cretaceous (Cenomanian)	Transgression: marine muds and silts. Block-faulting in Kangaroo Syncline. Incipient spreading ridge SW of Exmouth Plateau.
L. Cretaceous (Turonian - Coniacian)	Hiatus. Spreading, and transform fault across SW margin. Subsidence of Winning Group to bathyal depth S of transform fault.
L. Cretaceous (Santonian & Campanian)	Shallow-water carbonate sedimentation. Sinking of grabens in N area and erosion of Emu Spur.
L. Cretaceous (Maastrichtian) - E. Paleocene	Hiatus, probably due to increased current activity.
L. Paleocene - Eocene	Deep water carbonates with extensive gravity Formation of Exmouth Plateau Arch and uplift of Jurassic delta.
Eocene - e. Miocene	Hiatus, probably due to increased current activity. Formation of Cape Range Anticline.
E. Miocene - Recent	Continued subsidence; prograded shallow-water carbonates formed shelf. Renewed sedimentation on Emu Spur.

64

PETROLEUM GEOLOGY

No drilling has been carried out on the Exmouth Plateau, so this account of both its geological development and its petroleum potential are somewhat speculative. However the present study indicated that the area is fairly similar geologically to the remainder of the northern Carnarvon Basin. As the northern Carnarvon Basin contains some large gas fields and a small oil field (see 'Regional Setting'), the Exmouth Plateau must be regarded as prospective.

The broad Exmouth Plateau Arch is visible throughout the Triassic and younger sequence, and its Triassic culmination lies in nearly 1000 m of water about 270 km north-northwest of Exmouth, the nearest town on the Australian mainland. The culmination at the top of the Cretaceous sequence lies in somewhat shallower water (about 880 m) about 220 km from Exmouth. The shallowest water on the Plateau is 815 m deep.

Probably, because of the common cyclones, the only feasible way to develop major hydrocarbon fields on the plateau would be by pipelines to the mainland. Considering the length of the pipelines and the water depths involved it is quite apparent that only major fields, and very probably only oilfields, would be economic propositions.

At present the technology to produce hydrocarbons in such water depths has not been developed, but it should be adequate within the next five to ten years (Lockhead, 1973; see also 'Introduction').

Source Rocks

A major source of gas and minor source of oil in the Triassic sequence on the Rankin Platform is believed to be shale of the Jurassic-Dingo Claystone. Triassic shale is possibly a subsidiary gas source; and Cretaceous shale may be an oil source (Thomas & Smith, 1974). At Barrow Island,gas has been produced from sandstone within overpressured shales of the Dingo Claystone, and the shales themselves are believed to be the source rocks (Meath & Scott, 1973). Crank (1973) indicates that oil within sandstones in the relatively impermeable Cretaceous sequence of Barrow Island developed virtually in place from shales and siltstones within the Aptian-Turonian Winning Group (Muderong Shale, Windalia Radiolarite, Gearle Siltstone).

Thus almost all the shaly sequences of the Northwest Shelf are capable of producing hydrocarbons given sufficient depth of burial. On the basis of the variable wax content, the moderate pristane/phytane ratio (1.7-4.3) and the correlation index (30-65 at 250-300°C) Powell & McKirdy

(1973) suggested that the organic matter providing hydrocarbons in twelve Carnarvon Basin wells was a mixture of land plant debris and marine micro-organisms, deposited in near-shore marine environments, where reducing conditions made preservation possible.

On the Exmouth Plateau many of the shaly source rocks of the Northwest Shelf are probably present. Among likely sources are the Cretaceous Winning and Barrow Groups, the Jurassic Dingo Claystone, and shales within the Triassic Mungaroo Beds and Locker Shale. Possible sources within the older sequence include equivalents of the onshore Permian Byro Group and Callytharra Formation and possible shaly equivalents of largely marine onshore sandstone and carbonates of Silurian, Devonian, and Carboniferous age (see Thomas & Smith, 1974, for generalized descriptions of Carnarvon Basin sequences).

Table 5. Maturation of Hydrocarbons

Condition (after e.g. Reel & Griffin, 1971)	Sub-bottom depth (m)		Stratigraphic level on culmination x
	Northwest Shelf *	Exmouth Plateau ⊕	
Onset of hydrocarbon production (65°C)	1450	1750	Low in Jurassic
Onset of mature oil production (100°C)	2750	2750	High in Triassic
Maximum oil production (130°C)	3850	3600	Within Triassic
Onset of destruction of oil to form condensate and gas (150°C)	4700	4200	Within Triassic
Production of dry gas alone (180°C)	5700	5100	Lowest Triassic

* Average gradient assumed to be 2.7° C/100m (from well temperature logs). Immediate sub-bottom temperature assumed to be 25°C.

⊕ Average crustal thickness assumed to be 18 km compared to 23 km with respect to sea level on Northwest Shelf (Appendix III), to give an average gradient of 3.5° C/100m. Sub-bottom temperature assumed to be 5°C.

x Depths of horizons on Exmouth Plateau Arch Senonian culmination are: sea-bed 1050 m, Senonian 1740 m, Neocomian 2240 m, base Jurassic 3115 m, top Horizon G (?Permian) 6780 m.

Table 5 outlines possible average depths below the sea-bottom at which various stages in the production of hydrocarbons could be expected today, and relates it to the stratigraphic section below the culmination of the Exmouth Plateau Arch at the base of the Tertiary. These values are derived by extrapolation from an average value of temperature gradient for the Northwest Shelf, where values in fact vary considerably. No temperature-gradient measurements have been made on the plateau itself, and the gradient there probably varies considerably, so the results are no more than a general guide. With these provisos in mind, the results suggest that oil production can be expected from suitable Triassic and Jurassic source beds, and gas production from suitable Triassic and older source beds in parts of the plateau.

Around the plateau margins the depths of burial were insufficient to produce hydrocarbons from the Triassic and Jurassic sequences, assuming a gradient of around 3.5° C/100 m. However, in these marginal regions a number of large igneous bodies have been recognized in the seismic profiles and assuming that they are related to seafloor spreading, these bodies probably range from Early Jurassic to Late Cretaceous. Such intrusions may have increased the local temperature gradient, sufficiently to produce hydrocarbons from sequences that would otherwise have been too immature.

Another consideration is that the Cretaceous sequences (especially the Windalia Sand Member) which yield the oil at Barrow Island (see Crank, 1973) appear to have derived it from adjacent strata. In theory, they have not enough overburden (around 500 m) to produce hydrocarbons, nor does it appear likely that they ever did have. Thus organic-rich beds on the Northwest Shelf have apparently produced hydrocarbons, although theoretically not mature enough. The same situation could apply on the Exmouth Plateau.

In summary then, the conditions on the Exmouth Plateau seem favourable for the production of hydrocarbons from shaly sequences that are probably widespread vertically and horizontally.

Migration and entrapment

Considering the depths of burial discussed above it seems unlikely that hydrocarbons would have been produced in any abundance from organic matter in the Jurassic and younger sequences before Early Tertiary time. Such hydrocarbons are probably still being produced, as would appear to be the case with the Dingo Claystone in Barrow Deep No. 1 well. Progressively older sequences would have produced hydrocarbons progressively sooner, and thus one can imagine migration of hydrocarbons commencing in the Early

Mesozoic (Permian and older sources) and continuing through until the present. If the Jurassic is the major source sequence, much of the petroleum probably migrated in the Late Tertiary when the structure was little different to that of the present-day.

Little is known of the lithologies of the various sequences on the plateau, other than by analogy with the Northwest Shelf and the onshore Carnarvon Basin, and by extrapolations making use of palaeogeographic information. Older horizons will be within shorter drilling distance on the plateau than on the shelf because the younger sequences are thinner on the plateau.

Possible reservoirs would appear to include Silurian, Devonian, and Carboniferous sandstones and limestones, such as those occurring elsewhere in the Carnarvon Basin (see Thomas & Smith, 1974), sandstones in the Triassic fluvial to marginal marine Mungaroo Beds, sandstones within the deltaic Jurassic/Neocomian sequence (especially the Barrow Group), and Upper Cretaceous and Lower Tertiary marine limestones.

The Mungaroo Beds are excellent reservoirs on and near the Rankin Platform. They consist of interbedded sandstone and shale in highly variable proportions. The thickest petroleum producing sandstone section (310 m) was encountered at North Rankin No. 1, where porosities of up to 28 percent and permeabilities of up to 2200 millidarcies were measured (Kaye et al., 1972).

The bulk of the Jurassic sequence is likely to be shaly (Dingo Claystone) although prospective sandstones are quite likely constituents. The largely Neocomian Barrow Group is best known at Barrow Island where it consists of about 1100 m of dominantly coarse clastics - highly variable sandstones interbedded with shales and siltstones (Crank, 1973). At Barrow Island six sandstones within the group have yielded hydrocarbons but most of the reservoirs are thin and discontinuous; porosities exceed 20 percent but permeabilities are low. The Barrow Group appears to make up the bulk of the thick deltaic sequence on the southern Exmouth Plateau, the group having been laid down under similar conditions in both areas. The Barrow Island wells have sampled only a very small part of the sequence geographically, and good reservoir sands are probably developed within the group in other places.

The Upper Cretaceous and Lower Tertiary limestones of the Northwest Shelf have yielded hydrocarbons in a number of wells, but have very low permeabilities. Unless secondary alteration has increased their permeability on the Exmouth Plateau they do not appear to be attractive targets. Much of the Tertiary sequence on the plateau may consist of bathyal oozes, which normally have high porosities but low permeabilities, and hence could not be productive.

Several suitable impermeable sequences would make excellent cap-rocks. Among the best could be shales in the Triassic Mungaroo Beds, the Jurassic Dingo Claystone, the Lower Cretaceous Barrow Group, and the Lower to Upper Cretaceous Winning Group, and impermeable limestones in the Upper Cretaceous and Tertiary sequences. On the Rankin Platform the petroleum reservoirs of the Mungaroo Beds are capped by Jurassic and Cretaceous shales. The sequences and structures on the Exmouth Plateau which would be capped by Upper Cretaceous or Tertiary limestones are shown in Plate 3C.

Major exploration targets

The obvious target for initial exploration is the central part of the Exmouth Plateau Arch, on a culmination in the Triassic Mungaroo Beds. The arch is a very broad structure with closure roughly defined by the 3.0 second contour shown in Plate 5B. The horizontal closure is about 20 000 km^2 and the vertical closure is about 900 m, and the potential reservoir capacity, assuming an average pay column of 300 m and an average porosity of about 10 percent is about 500 km^3 of oil. This shows that a mammoth field is within the bounds of possibility.

It is likely that the tilted fault-blocks within the arch will have to be considered one by one. Although these structures are inadequately defined by the seismic coverage, they are very large (see Pls. 5B and 12) with widths of 10 to 20 km, lengths considerably longer than their widths, and vertical closures of as much as 300 m. Such structures are larger than individual blocks of the Rankin Platform, and could conceivably contain giant petroleum fields. Jurassic and Cretaceous shales draped over the Triassic blocks would probably be one trapping element, and shales laterally juxtaposed across normal faults would probably be the other element, as on the Rankin Platform.

Source rocks supplying hydrocarbons to the Mungaroo Beds in the central area could be older sediments, shales within the beds themselves, or shales in laterally adjacent Jurassic and Neocomian sequences. The individual blocks formed in the Early Mesozoic, but the regional Exmouth Plateau Arch probably did not form until the Late Tertiary (see Structural Evolution). Even the southerly slope south of 20°S probably did not develop until Jurassic time when the Dingo Claystone/Barrow Group delta caused downwarping. Thus any hydrocarbons migrating in Palaeozoic or even Mesozoic time would have had very different migration paths to those prevailing at present.

The thick Barrow Group deltaic sequence slightly south of the culmination of the Exmouth Plateau Arch (Pl. 6B) is another major target containing potential source and reservoir rocks. This area is much less faulted than is the central and northern part of the arch and an initial test on the culmination of the group near 113°E, 20°20'S (Plate 11) is a logical beginning. Sands within this deltaic sequence are likely to be lenticular, and stratigraphic traps should predominate, making exploration more difficult than in the Mungaroo Beds.

The delineation of other targets must await the results of more siesmic work, and the drilling of exploration wells in the central, shallow-water part of the plateau. The area is enormous, and numerous targets are possible, both structural and stratigraphic.

Conclusions

Suitable petroleum source rocks, especially Triassic to Neocomian shales and siltstones, and suitable reservoir rocks, especially Triassic and Neocomian sandstones, appear to exist in the Exmouth Plateau region, where as much as 10 km of prospective sediment rests on basement. Whether the depth of burial has been adequate to generate hydrocarbons from Jurassic and Neocomian shaly sequences depends on the temperature gradient in the area. If it were similar to the average gradient on the Northwest Shelf, major formation of hydrocarbons would be largely confined to Triassic and Palaeozoic source rocks. However the gradients on the Plateau are probably as variable as those on the Shelf, in which case generation from the younger sequences would be possible in places.

The area is structurally very complex, especially at the level of Horizon F, which probably represents an Early to Middle Jurassic unconformity. Structures are large enough to be attractive targets even in the prevailing water depths of more than 815 m. Because of technological limitations it seems likely that the first exploration wells will be drilled in the central part of the plateau, in water shallower than 1200 m.

Prime targets are the numerous large Horizon F fault-blocks, which probably contain Triassic sandstones of the Mungaroo Beds, sealed by Jurassic and Cretaceous shales. Possibly the best such targets lie on the broad Exmouth Plateau Arch. However this arch may have developed only in the Late Tertiary, in which case it would have formed a focus only for hydrocarbons migrating later.

Another major exploration target is the extensive Jurassic to Neocomian delta on the southern Exmouth Plateau, which has a culmination near 113°E, 20°20'S. Deltaic sands would almost certainly have had to obtain their hydrocarbons from within the deltaic sequence, whose depth of burial may possibly have been inadequate for hydrocarbon generation. 70

Given the water depths and the distance of the prime targets from shore (more than 200 km) exploration and development will be expensive and difficult. The economic factors suggest that only major fields would be of interest, and possibly only oil fields. Landed costs would be well in excess of those prevailing for Australian crude oil in 1975.

Despite these problems it is likely that some petroleum exploration wells will be drilled on the Exmouth Plateau once adequate technology (see 'INTRODUCTION') is developed, possibly within five years. In the meantime further seismic exploration must be carried out to enable drilling targets to be adequately defined, and a program of geological sampling would substantially increase our knowledge of the area's history and prospectivity.

RECOMMENDATIONS

It is inevitable that this area will be drilled, but it is unlikely that the first holes in such deep water will be completed before 1980. If the general stratigraphy, structure, and geological history could be adequately defined in the meantime, exploration efforts would be greatly aided because the most prospective areas for petroleum could be better delineated. The authors recommend regional seismic and geological programs to enable a complete regional picture to be built up before drilling. We also recommend a semi-detailed seismic program to delineate major structures which could become structural targets for drilling programs.

Further seismic surveys

The present seismic line spacing is too wide to allow firm correlation of the fault zones which are visible in the deeper sedimentary sequences, so that accurate regional maps of these sequences cannot be built up. The maximum suitable line spacing to overcome this problem is 15 km (8 nautical miles), and most of the area could be covered with 20 000 km (11 000 nm) of surveys. Most lines should run northwest-southeast, normal to the prevailing regional structure. This would allow a reliable regional interpretation of the geometry of the entire area than at present. The surveying would need to be carried out before delineation of drilling targets to obtain maximum value from it, and an interpretation team should aim to publish the major results within 18 months of completion of the survey.

It is further suggested that another 5000 km (3000 nm) of closely spaced seismic lines be run over the most prospective areas, either at the close of the regional survey, or shortly thereafter. This would enable mapping of individual blocks and fault zones thought to be representative of the area, and help to define drilling targets.

71

In these two surveys the gathering of high-quality seismic data would be of prime importance. Magnetic and gravity recording could also be carried out for little additional cost and this would allow resolution of structures with wavelengths down to 20 km. Total ship time would approach six months. For the regional survey a boat speed of about 6 knots would reduce cable noise to an acceptable level, and navigational accuracy of 1 km should suffice. An airgun system would have better frequency distribution than the sparker system used in the past and hence should give better penetration. A CDP recording configuration would enable stacking in shallow water, permitting reliable ties to wells on the continental shelf.

The total cost of the two programs including processing should be $2 000 000-$3 000 000, which is cheap when one considers the petroleum potential of this vast area.

Geological sampling

The present evaluation of seismic data has shown that pre-Tertiary rocks crop out in at least four different areas around the margins of the Exmouth Plateau where the continental slope is steep. Tentative ages have been placed on these outcrops by long-distance correlation to wells hundreds of kilometres away. If the outcrops were sampled many of them could probably be dated palaeontologically, and a picture of the environment of deposition could be built up. This would enable a more confident unravelling of the complex history of the area, allowing better planning of future exploration.

A six-week program of sampling using dredges, piston-corers, and a small drill would probably be adequate for this purpose. Problems would include the depth of water (1500-3000 m) and the probable existence of a patchy cover of recent talus.

Sampling of the Cainozoic carbonate sequence should be carried out as a complementary program. Samples could be taken while steaming from area to area, and an additional time of 2 weeks would probably be sufficient. This would enable accurate dating of the Cainozoic reflectors, and environmental analysis of the various Cainozoic sequences. In our reconstruction of the geology of the area, a major unresolved question is the depth of water during Cainozoic deposition. If this were known, much more reliable predictions of the geological development and petroleum potential of the area could be made. The Cainozoic sequence is probably only weakly consolidated, and piston-coring should give good results. Some heat-flow measurements would greatly assist in predicting hydrocarbon maturation levels on the plateau.

The cost of a two-months program would be about $200 000. This would give data with a broad geographic spread compared to, say, one deep stratigraphic drill hole which would cost perhaps ten times as much. Such a program should ideally be carried out at about the same time as the regional seismic program.

Petroleum drilling

From the data available to us it appears that the most prospective sequences are the Triassic Mungaroo Beds and the Upper Jurassic/Neocomian sequence, both of which have yielded petroleum on the Northwest Shelf. Both can be satisfactorily tested in water shallower than 1000 m near 113°E, 20°20'S. Drilling petroleum exploration wells in such water depths should be possible about 1980, and production a few years thereafter (see 'INTRODUCTION').

The Mungaroo Beds are extensively faulted in the central Exmouth Plateau area and large traps, similar to those of the Rankin Platform, appear to be present. Sandstone reservoirs in the beds would hopefully be sealed by younger shales. Once the blocks have been better defined by further seismic work, the most likely targets can be picked out. In the central area the top of the block-faulted Triassic sequence (Horizon F) is covered by about 2100 m of younger sediments; at least the first hole should be programmed to more than 4000 m below the sea-bed to adequately test the entire Triassic sequence. A 5000 m well sited above the Palaeozoic monocline at about 112°55'E, 20°05'S would penetrate 1000 m into the sequence below Horizon G, (possibly Permian) and yield valuable stratigraphic information about the deeper sequences which may themselves by prospective.

The thick Jurassic/Neocomian delta in the southern part of the area has a broad culmination at 113°E, 20°20'S. Although one test of this sequence, which probably contains lenticular sandstone reservoirs, would not be sufficient a hole at this locality would be a logical early step in exploration.

In fact, it might be possible to site a single hole to penetrate a culmination in the Cretaceous Winning Group, the Jurassic/Neocomian culmination, a Triassic fault-block, and the Palaeozoic culmination. Not only would this be a useful petroleum exploration well but, with an adequate coring program, would yield a great deal of stratigraphic information about a virtually unknown sequence.

73

REFERENCES

AUDLEY-CHARLES, M.G., 1968 - The geology of Portuguese Timor. Geol. Soc. Lond. Mem. 4

ANDERSON, A.P., 1974 - Deep water drilling with the SEDCO-445, offshore Java. Indonesian petrol. Assoc., 3rd ann. Conv., 1974.

BECK, R.H., 1972 - The oceans, the new frontier in exploration. APEA J., 12(2), 7-28.

BOEUF, M.G., & DOUST, H., 1975 - Structure and development of the southern margin of Australia. APEA J., 15(1), 33-43.

CGG (COMPAGNIE GENERALE DE GEOPHYSIQUE) 1975 - Geophysical Surveys of the Continental Margins of Australia, Gulf of Papua and the Bismarck Sea, October 1970 to January 1975, Operations and Techniques. A report by Compagnie Generale de Geophysique for the Bureau of Mineral Resources. Bur. Miner. Resour. Aust. Rec. 1975/151 (unpubl.).

CHALLINOR, A., 1970 - The geology of the offshore Canning Basin, Western Australia. APEA. J., 10(2), 78-90.

CONDON, M.A., 1968 - The geology of the Carnarvon Basin, Western Australia. Part 3: Post-Permian stratigraphy; structure; economic geology. Bur. Miner. Resour. Aust. Bull. 77.

CRANK, K., 1973 - Geology of Barrow Island oil field. APEA J., 13(1), 49-57.

DAVIES, T.A., WESER, E.O., LUYENDYK, B.P., & KIDD, R.B., 1975 - Unconformities in the sediments of the Indian Ocean. Nature 253, 15-19.

ESSO (ESSO AUSTRALIA LTD), 1972 - Final operations Report: Indian Ocean, Offshore Western Australia E71A. Marine Seismic Survey by Western Geophysical Company. Unpubl. Co. Rep.

EXON, N.F., & WILLCOX, J.B., in prep. - The regional geology of the Exmouth Plateau and adjacent areas. Bur. Miner. Resour. Aust. Bull.

FAIRBRIDGE, R.W., 1955 - Some bathymetric geotectonic features of the eastern part of the Indian Ocean. Deep-Sea Res., 2, 161-71.

FALVEY, D.A., 1974 - The development of continental margins in plate tectonic theory. APEA J., 14(2), 95-106.

FALVEY, D.A., & VEEVERS, J.J., 1974 - Physiography of the Exmouth and Scott Plateaux, Western Australia, and adjacent northeast Wharton Basin. Mar. Geol., 17, 21-59.

GEARY, J.K., 1970 - Offshore exploration of the southern Carnarvon Basin. APEA J., 10(2), 9-15.

GULF (GULF RESEARCH AND DEVELOPMENT COMPANY), 1973 - Regional geophysical reconnaissance off the northern coast of Western Australia, Parts I & II. Unpubl. Co. Rep.

HAYES, D.E., FRAKES, L.A., et al., 1973 - Leg 28 deep-sea drilling in the southern ocean. Geotimes 18(6), 19-24.

74

HEEZEN, B.C., 1974 - Atlantic-type continental margins. In BURK, C.A., & DRAKE, C.L., (Eds.) - The geology of the continental margins. Springer-Verlag, 13-24.

HEEZEN, B.C., & THARP, M., 1966 - Physiography of the Indian Ocean. Phil. Trans. Roy. Soc. Lond. Ser. A., 259, 137-49.

HOGAN, A.P., & JACOBSON, E.P., 1975 - Geophysical results from the northwest Australian continental margin. Bur. Miner. Resour. Aust. Rec. 1975/101 (unpubl.).

JONES, H.A., 1971 - Late Cenozoic sedimentary forms on the northwest Australian continental shelf. Mar. Geol.,10, M20-6.

JONES, H.A., 1973 - Marine geology of the northwest Australian continental shelf. Bur. Miner. Resour. Aust. Bull. 136.

KAYE, P., EDMOND, G.M., & CHALLINOR, A., 1972 - The Rankin Trend, Northwest Shelf, Western Australia. APEA J., 12(1), 3-8.

KENNETT, J.P., BURNS, R.E., et al., 1972 - Australia-Antarctic continental drift, palaeocirculation changes and Oligocene deep-sea erosion. Nature Phys. Sci., 239, 51-5.

KONECKI, M.C., GARTLAND, C.F., & SKEGGS, A.S., 1972 - Australia's petroleum resources, production and demand in the 1970s. APEA J., 12(1), 110-15.

LOCKHEED (PETROLEUM SERVICES LTD)., 1973 - BACKGROUNDER: Lockheed Petroleum Services' Subsea system, Oct. 1973. Letter on BMR file 73/1405.

MARKL, R.G., 1974 - Evidence for the breakup of eastern Gondwanaland by the early Cretaceous. Nature, 251, 196-200.

MEATH, J.R., & SCOTT, R.J., 1973 - Barrow Deep No. 1 well completion report, Barrow Island, Carnarvon Basin.P.L. 1-H. WAPET Rep. (unpubl.).

NATIONAL PETROLEUM COUNCIL, 1969 - Petroleum resources under the ocean. National Petroleum Council, Washington.

OGJ, 1975 - SEDCO to build $50 million drillship. Oil Gas J., 73(19), 48.

POWELL, D.E., 1973 - Hydrocarbon occurrences offshore from the Pilbara Block. Aust. Inst. Min. Metall. Conf. Pap., W. Aust., 1973, 193-203.

POWELL, T.G., & McKIRDY, D.M., 1973 - Relationship between ratio of pristane to phytane, crude oil composition and geological environment in Australia. Nature phys. Sci., 243(124), 37-9.

QUILTY, P.G., 1974 - Tertiary stratigraphy of Western Australia. J. geol. Soc. Aust. 21(3), 301-18.

REEL, D.A., & GRIFFIN, G.A., 1971 - Why most of the Florida Peninsula remains dry is not fully explained. Oil Gas J., Nov. 1971.

RONA, P.A., 1973 - Worldwide unconformities in marine sediments related to eustatic changes of sea level. Nature. phys. Sci., 244, 25-6.

75

SCLATER, J.G., & FISHER, R.L., 1974 - Evolution of the east central Indian Ocean, with emphasis on the tectonic setting of the Ninetyeast Ridge. Bull. geol. Soc. Am., 85, 683-702.

SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1974 - Deep sea drilling project. Scripps Inst. tech. Pamphlet., 4pp.

SEDIMENTARY BASINS STUDY GROUP, 1974 - Summary of Phanerozoic sedimentary basins in Australia and adjacent regions, 1974. Bur. Miner. Resour. Aust. Rec. 1974/178 (unpubl.).

SHELL (SHELL DEVELOPMENT (AUSTRALIA) PTY LTD), 1972 - Interpretation report on marine geophysical survey offshore Australia conducted with M.V. Petrel (from 7 June to 25 August 1971). Unpubl. Co. Rep.

THOMAS, B.M., & SMITH, D.N., 1974 - A summary of the petroleum geology of the Carnarvon Basin. APEA. J., 14(2), 66-76.

VEEVERS, J.J., 1971 - Phanerozoic history of Western Australia related to continental drift. J. Geol. Soc. Aust., 18(2), 87-96.

VEEVERS, J.J., 1973 - Stratigraphy and structure of the continental margin between North West Cape and Seringapatam Reef, northwest Australia. Bur. Miner. Resour. Aust. Bull. 139.

VEEVERS, J.J. (ed.), 1975 - Deep sea drilling in Australasian waters. Challenger Symposium, Sydney.

VEEVERS, J.J., & EVANS, P.R., 1973 - Sedimentary and magmatic events in Australia and the mechanism of world-wide Cretaceous transgressions. Nature phys. Sci., 245, 33-6.

VEEVERS, J.J., FALVEY, D.A., HAWKINS, L.V., & LUDWIG, W.J., 1974 - Seismic reflection measurements of northwest Australian Margin and adjacent deeps. Bull. Am. Assoc. Petrol. Geol., 58(9), 1731-50.

VEEVERS, J.J., & HEIRTZLER, J.R., et al., 1973 - Deep sea drilling project, Leg 27 in the eastern Indian Ocean. Geotimes, 18(4), 16-17.

VEEVERS, J.J., & HEIRTZLER, J.R., 1974 - Tectonic and palaeogeographic synthesis of Leg 27. Initial Reps. D.S.D.P., XXVII, 1049-1054.

VEEVERS, J.J., HEIRTZLER, J.R. et al., 1974 - Initial reports of the deep sea drilling project, Vol XXVII. National Science Foundation, USA.

VEEVERS, J.J., & JOHNSTONE, M.H., 1974 - Comparative stratigraphy and structure of the Western Australian margin and the adjacent deep ocean floor. Initial Reps. D.S.D.P., XXVII, 571-585.

VEEVERS, J.J., JONES, J.G., & TALENT, J.A., 1971 - Indo-Australian stratigraphy and the configuration and dispersal of Gondwanaland. Nature, 229, 383-388.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 60.

WATKINS, N.D., & KENNETT, J.P., 1973 - Response of deep-sea sediments to changes in physical oceanography resulting from separation of Australia and Antarctica. In TARLING, D.H., & RUNCORN, S.K. (eds.) - Implications of continental drift to the earth sciences - Volume 2. Academic Press

WHITEMAN, A.J., 1968 - The formation of the Red Sea depression. Geol. Mag., 105, 231-46.

WHITWORTH, R., 1969 - Marine geophysical survey of the north-west continental shelf, 1968. Bur. Miner. Resour. Aust. Rec. 1969/99 (unpubl.).

WILLCOX, J.B., 1974 - Geophysical results from the Great Australian Bight. Bur. Miner. Resour. Aust. Rec. 1974/147 (unpubl.).

WILLCOX, J.B., & EXON, N.F., 1976 - The regional geology of the Exmouth Plateau. APEA J., 16(1).

WILLCOX, J.B., EXON, N.F., & PETKOVIC, P., in prep. - Exmouth Plateau depth and thickness maps. Bur. Miner. Resour. Aust. Rec.

WILLCOX, J.B., EXON, N.F., PETKOVIC, P., & PETKOVIC, J., 1975 - The Exmouth Plateau. In BMR Geophysical Branch Annual Summary of Activities for 1974. Bur. Miner. Resour. Aust. Rep. 190.

WORSLEY, T.R., 1971 - Terminal Cretaceous events. Nature, 230, 318-20.

WORSLEY, T.R., 1974 - The Cretaceous-Tertiary boundary event in the ocean. In Studies in palaeo-oceanography. Soc. Econ. Palaeont. Mineralog. spec. Publ., 20, 94-125.

77

APPENDIX I

COMPUTATION OF FREE-AIR, BOUGUER, AND MAGNETIC ANOMALIES

The free-air anomaly is computed by applying latitude and Eötvös corrections (Glicken, 1962) to the observed gravity data. Essentially, it shows the differences between the gravity observed at sea level on a stationary platform, and theoretical gravity on the reference spheroid. It depicts the gravity effect of structures below sea level.

$$G_{FAA} = G_{OBS} - 978.049\,(1 + 0.0052884 \sin^2 \phi - 0.000005 \sin^2 2\phi) + 7.5\,Ve$$

where G_{FAA} = free-air anomaly

G_{OBS} = observed gravity

ϕ = latitude

Ve = eastward component of velocity in knots

In the Bouguer anomaly corrections have been applied to eliminate the gravity effect caused by variations in water depth. The water layer of density 1.03 g/cm^{-3} has been replaced with a layer density 2.20 g/cm^{-3}, which is assumed to be the density of sediments on the sea-bed. The Bouguer anomaly ideally shows the gravity effect of structures beneath the sea-bed.

$$G_{BA} = G_{FAA} + 2\pi G \Delta\rho\, d$$

where G_{BA} = Bouguer anomaly

G = Universal Gravitational constant

$\Delta\rho$ = difference in density between water and sediments, assumed to be 1.2 g/cm^{-3}

d = water depth in metres

The magnetic anomalies presented by Hogan & Jacobson (in prep.) were computed as the difference between the measured total field, corrected for diurnal variation, and the International Geomagnetic Reference Field (IGRF). However, when we attempted to produce a composite magnetic anomaly map based on data from the Continental Margin Survey and the 1968 Sparker Survey (Whitworth, 1969) the two were found to be incompatible. In the Exmouth Plateau area it appears that the annual change in total intensity (time terms) used in calculating the IGRF differs considerably from the actual annual changes in the area. At several primary magnetic stations the IGRF and the observed field are diverging year by year, and had diverged by approximately 500 NT from 1968 to 1972. Consequently, the magnetic anomalies (Pl. 7) were computed with reference to a regional field which more closely fits the observations in the Australian region. This is termed the Australian Geomagnetic Reference Field (AGRF) and is computed and discussed in detail by J. Petkovic (in prep.).

(magnetic anomaly) = (observed total magnetic field)
-(diurnal - (AGRF)

References

Glicken, M., 1962 - Eötvös corrections for a moving gravity meter. Geophysics, 27, 531-3.

Hogan, A.P., & Jacobson, E.P., in prep. - Geophysical results from the northwest margin. Bur. Miner. Resour. Aust. Rec.

Petkovic, J.J., in prep. - Australian Geomagnetic reference field - a spherical harmonic analysis of secular variations, 1960-1975. Bur. Miner. Resour. Aust. Rec.

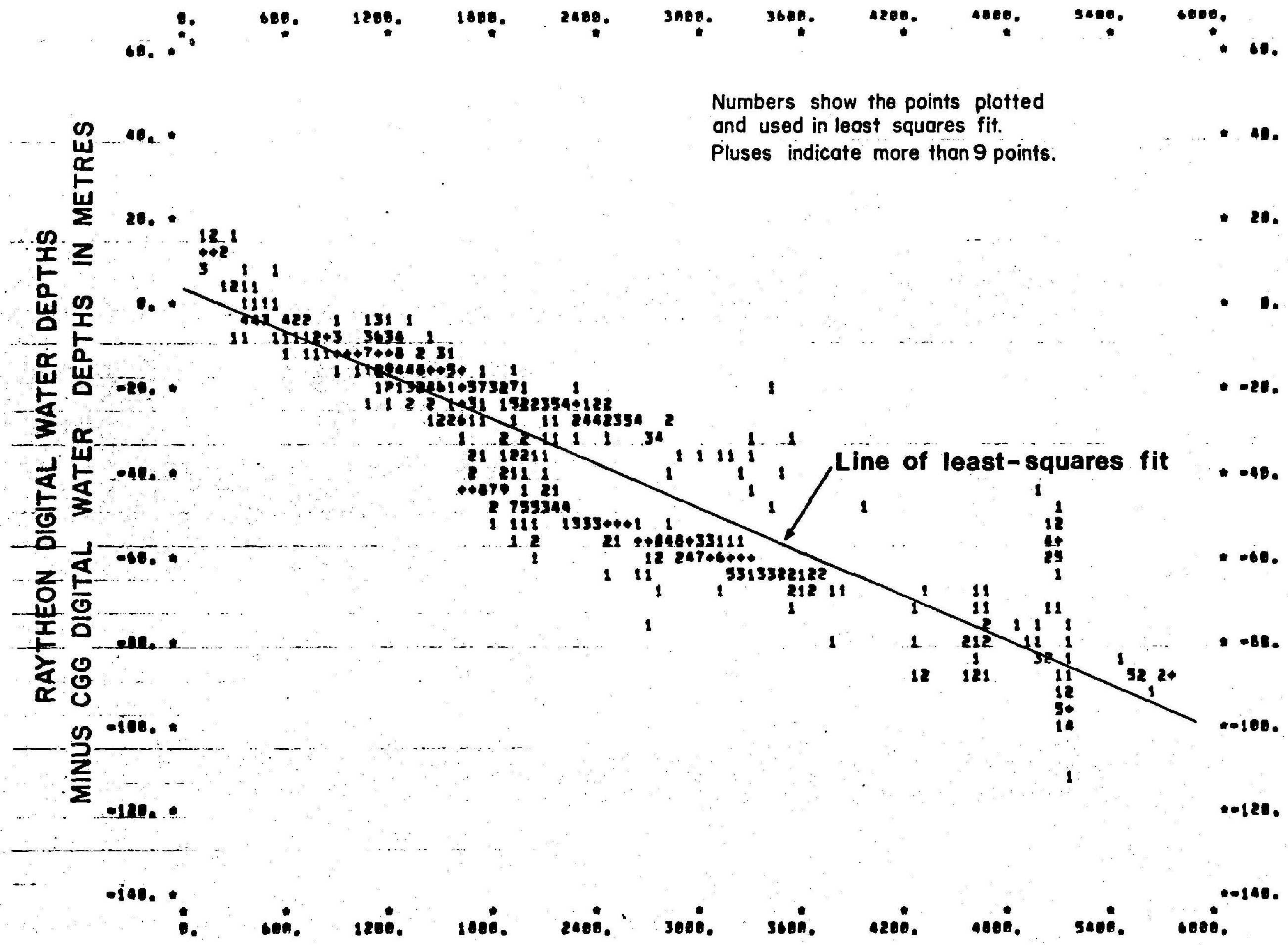
Whitworth, R., 1969 - Marine geophysical survey of the northwest continental shelf, 1968. Bur. Miner. Resour. Aust. Rec. 1969/99 (unpubl.).

RECORD No 1975/158

COMPARISON OF WATER DEPTH DATA FROM TWO SOURCES

EXMOUTH PLATEAU

APPENDIX II



C.G.G. DIGITAL WATER DEPTHS IN METRES
(Derived largely from the Elac Fathometer and seismic records by Compagnie Generale de Geophysique.)

WA/88-67A

80

FIG. A

APPENDIX III

COMPUTATION OF CRUSTAL THICKNESSES

A crude estimate of crustal thickness has been obtained from the free-air anomalies along Line BMR 17/068, which extends from the continental shelf to the outer continental slope and is believed to cross structures fairly typical of the area. The computation involves the following assumptions:-

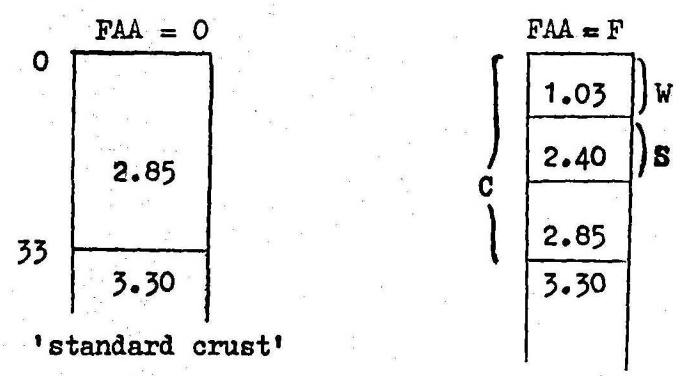
(i) Owing to the absence of crustal thickness determination from seismic methods it has been necessary to introduce a 'standard crust'. We have used the most usually accepted model of a 32 km crust giving rise to zero free-air anomaly. Densities of crust and mantle are taken as 2.85 and 3.30 g/cm^{-3} respectively in this model.

(ii) The free-air anomalies along the profile are caused by differences in mass of the crustal column and standard column at any point. The assumed densities of water, sedimentary section, crust and mantle are 1.03, 2.40, 2.85, and 3.30 g/cm^{-3}, respectively.

(iii) A slab model is a sufficient approximation for computing the gravity effect of each layer.

(iv) Where the thickness of the sedimentary section cannot be measured it is assumed to be 10 km.

Formula for crustal thickness



A 1 km thick slab of density 1.00 g/cm^{-3} has a gravity effect of 41.9 mGal. The difference in gravity effect of the two columns,

$$F = 41.9\left[1.03W + 2.40S + 2.85\,(C - W - S) + 3.30\,(33 - C)\right] - 41.9\left[(2.85.33)\right]$$

$$F/41.9 = 1.03W + 2.40S + 2.85C - 2.85W - 2.85S + 108.90 - 3.30C - 94.05$$

$$0.45C = 14.85 - 1.82W - 0.45S - 0.024F$$

The value 14.85 is directly related to the choice of 33 km as standard crustal thickness. A change to say 30 km would reduce all computed thickness by 3 km but differences between values would remain unchanged.

TABLE A. Crustal thicknesses along Line BMR 17/068 *

station SS DD HH MM	water depth (W)	sediment thickness (S)**	free-air anomaly (F)	crustal thickness (C)	
17441600	4.091	0.200	- 9.3	16.8	Outer Continental Slope
1700	4.016	0.746	-18.9	17.0	
1800	4.000	1.291	-32.5	17.3	
1900	2.865	1.837	- 6.0	19.9	
2000	2.310	2.588	- 7.2	21.5	
2100	2.050	3.762	- 7.0	21.3	
2200	2.200	(5.000)	-10.1	19.6	
3300	2.200	(6.000)	-18.8	19.1	
17450000	2.200	(7.000)	-33.8	18.9	
0100	2.060	(8.000)	-32.4	18.4	
0200	1.910	(9.000)	-30.4	17.9	
0300	1.740	(10.000)	-25.3	17.3	
0400	1.660	"	-25.2	17.6	
0500	1.410	"	-21.1	18.4	
0700	1.240	"	- 3.2	18.2	
0800	1.200	"	- 3.1	18.3	
0900	1.160	"	- 4.2	18.5	
1000	0.980	"	- 0.7	19.1	Exmouth Plateau crest
1100	0.940	"	- 2.7	19.3	
1200	0.950	"	- 5.7	19.5	
1300	0.960	"	- 9.9	19.6	
1400	1.000	"	-11.9	19.6	
1500	1.080	"	-17.6	19.2	
1600	1.170	"	-30.7	19.9	
1700	1.110	"	-33.2	20.3	
1800	1.115	"	-40.0	20.5	
1900	1.240	"	-45.4	20.4	
2000	1.320	"	-51.9	20.4	
2100	1.300	"	-53.7	20.6	
2200	1.300	"	-51.4	20.5	
2300	1.290	"	-45.9	20.3	
17460000	1.210	"	-40.9	20.3	
0100	1.120	"	-29.1	20.0	
0200	0.245	"	16.9	21.1	

82

Table A (Contd)

station SS DD HH MM	water depth (W)	sediment thickness (S)**	free-air anomaly (F)	crustal thickness (C)
17460300	0.105	(10.000)	47.5	20.1
0400	0.072	"	57.9	19.6
0500	0.077	"	62.9	19.4
0600	0.073	"	64.7	19.3
0700	0.071	"	25.9	20.8
0800	0.068	"	3.6	22.5
0900	0.062	"	-17.6	23.7
1000	0.058	"	-26.4	24.2
1100	0.057	"	-22.0	24.1
1200	0.062	"	-24.6	24.1

Rankin Platform

Continental Shelf

* All depths in kilometres

** Bracketed values are estimated thicknesses only

APPENDIX IV

SEISMIC INTERVAL VELOCITIES FOR TIME TO DEPTH CONVERSION

Velocity and depth determinations were carried out on refraction events occurring on nine BMR sonobuoy records from the Exmouth Plateau area (Tables B & C). It was found that refractors giving rise to similar velocities could be broadly related to layers bounded by the same seismic reflecting horizons, and consequently it was possible to compute an average (refraction) velocity for each layer, which was regarded as the interval velocity for that layer. The average velocities obtained are in reasonable agreement with those derived from sonobuoy records by Veevers et al. (1974). In their analysis use was made of the refractions and also the high angle reflections, according to the technique described by Le Pichon et al. (1968). From the Jurassic upwards (post seismic reflection F) the velocities derived from sonobuoys on the Exmouth Plateau are considerably less than those derived from wells along the edge of the continental shelf. This could result from a greater proportion of pelagic ooze on the Plateau, in which high porosity gives rise to relatively low velocities. Table C shows the relationship between seismic reflectors and interval velocities derived from well velocity shoots and sonobuoy records, together with the most suitable velocities for conversion from time to depth.

The interval velocities determined from well shoots in three nearby wells are related to the stratigraphy in Figures B, C & D, and this information is summarized in Figure E. These figures were derived from the relevant well completion reports submitted by the exploration companies under the Petroleum Search Subsidy Acts.

References

Le Pichon, X., Ewing, J. and Houtz, R.E., 1968 - Deep Sea sediment velocity determination made while reflection profiling. Jour. Geophys. Research, V. 73, pp. 2597-2614.

Veevers, J.J., Falvey, D.A., Hawkins, L.V. and Ludwig, W.J., 1974 - Seismic reflection measurements of northwest Australian margin and adjacent deeps. Bull. Amer. Assoc. Pet. Geol., V. 58, No. 9, pp. 1731-1750.

Table B. Location of BMR Sonobuoys

No	Line	Time (DD.HHMM)	Approx. location	
			Lat.	Long.
1	17/074	56.0143-56.0250	18°25'S	115°50'E
2	17/093	82.0510-82.0640	17°35'S	117°15'E
3	17/084	75.1403-75.1530	15°50'S	119°25'E
4	17/090	80.2337-81.0051	15°20'S	119°55'E
5	17/089	80.1240-80.1400	14°25'S	121°10'E
6	17/076	59.2244-60.0013	17°25'S	116°25'E
7	17/079	65.2235-66.0103	16°55'S	116°25'E
8	17/072	54.0217-54.0314	18°55'S	114°10'E
9	18/007	07.0547.07.615	17°55'S	113°30'E

TABLE C. Comparison of seismic velocities from well velocity shoots and sonobuoys

Seismic reflectors	Wells Seismic velocities from well shoots	Sonobuoys Plateau & edge zone Veevers et al.,1974	Sonobuoys Plateau & Continental Slope, BMR Margins Survey	Seismic velocities selected for depth conversions
Seabed-----				
	2733 Malus,N.Tryal Rocks & W. Tryal Rocks	2200 range 2000-2500; average of 6 interval velocities	2350 range 2020-2700; average of 2 refraction velocities	2300
R3---------C				
	2866 Malus,N.Tryal Rocks & W. Tryal Rocks	2500	2525 range 2480-2570; average of 2 refraction velocities	2500
D				
	3920	range 2400-2700; average of 3 refraction & 3 interval velocities	3033 range 2840-3220; average of 3 refraction velocities	3500
R4---------F	Malus,Egret,Angel, Dampier & Legendre			
		3150*	3025**	
- - - - -	- - - - -	- - - - -	- - - - -	- - - - -
G	4000 Rankin & Goodwyn	3700 - 4800 refraction velocities	3880 range 3460-4330 average of 3 refraction velocities	4000

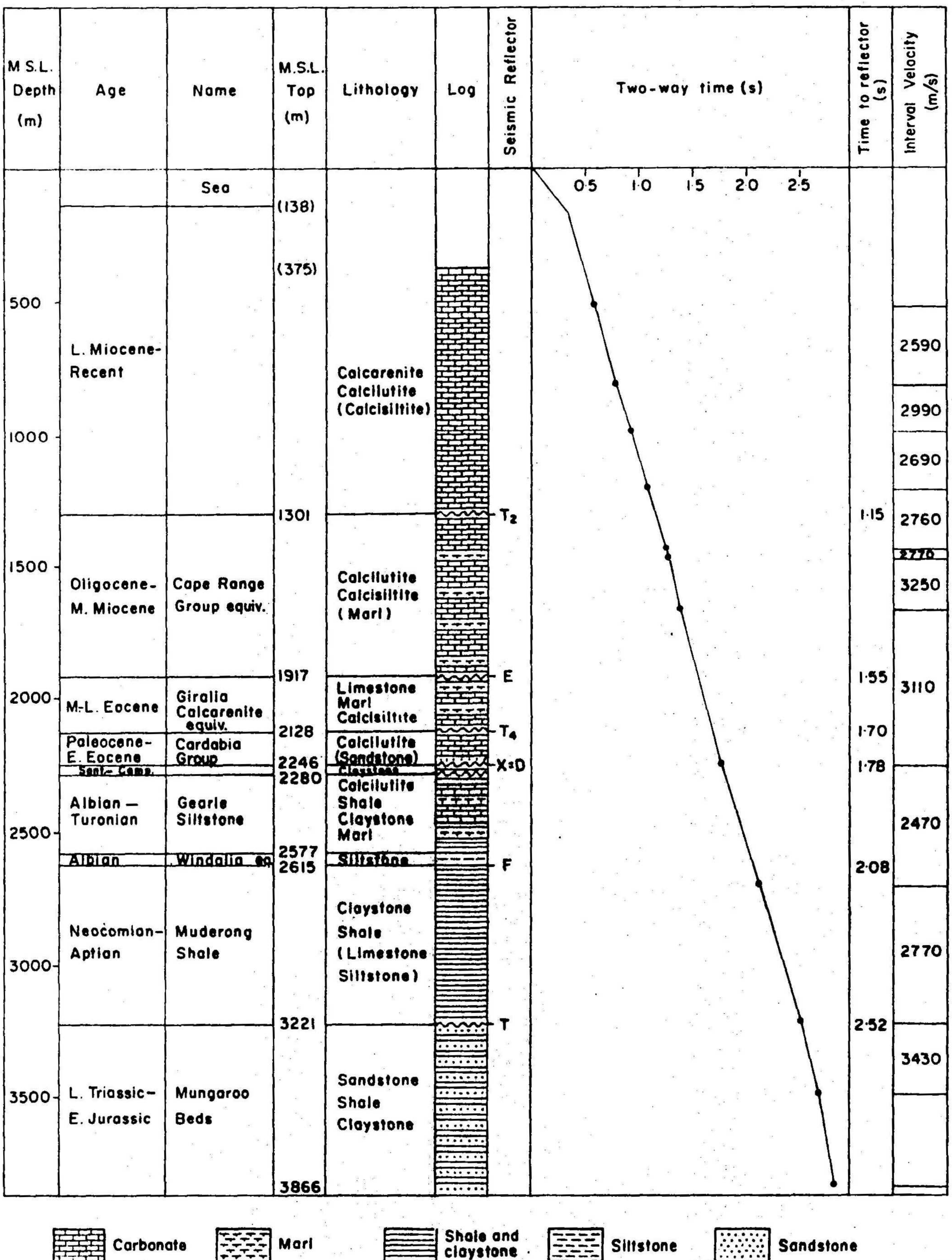
* Range 2800-4000; average of 8 refraction and 3 interval velocities

** Range 2900-3460; average of 4 refraction velocities
Value 3850 m/s determined from sonobuoy 6 has been excluded as it relates to older ? Triassic section.

All figures give velocities in metres per second

98

FIG. B



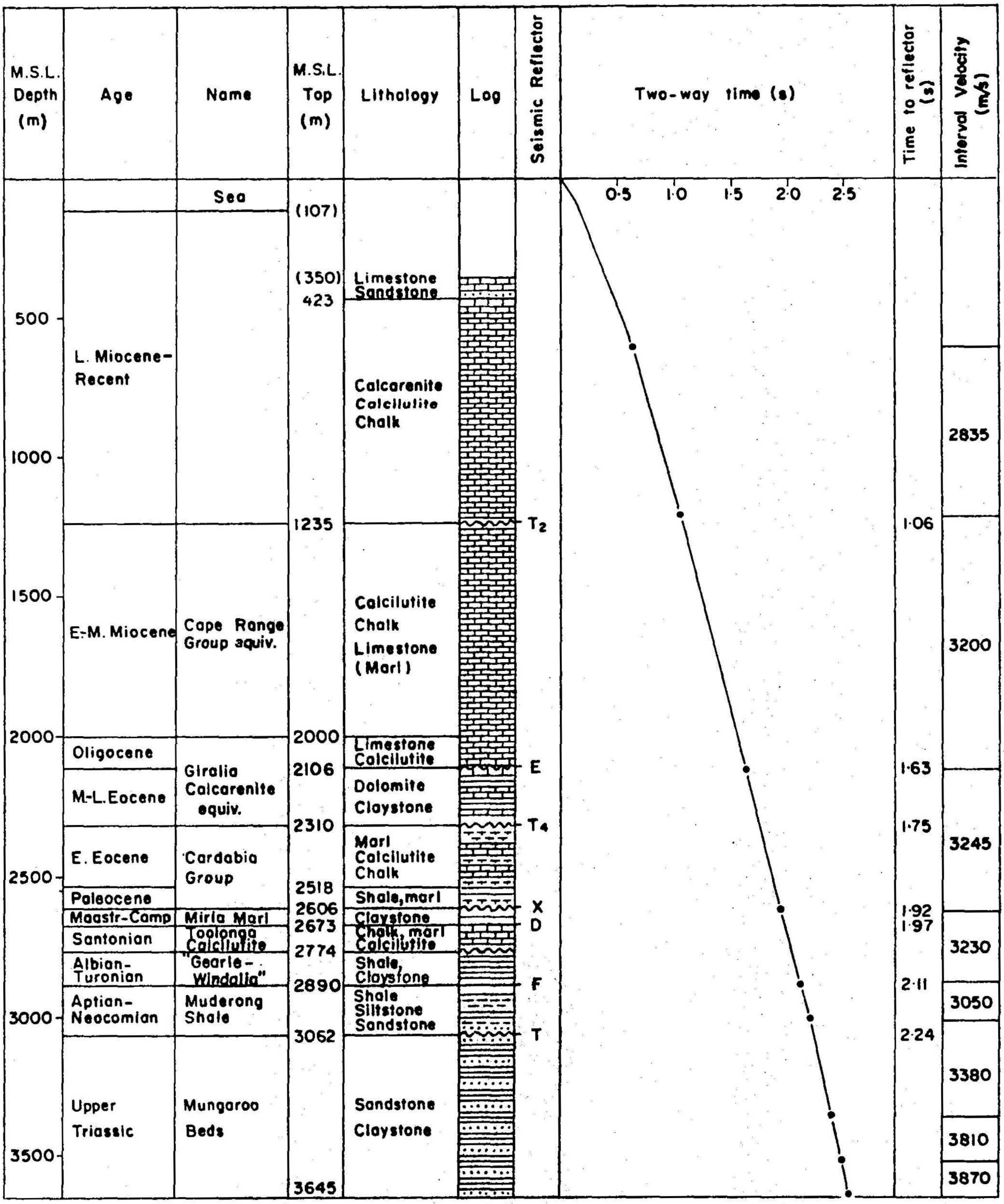
87

WAPET WEST TRYAL ROCKS No. I LOG

RECORD No 1975/158

E50/B8-43A

FIG. C



Note: Lithological key on Figure 3

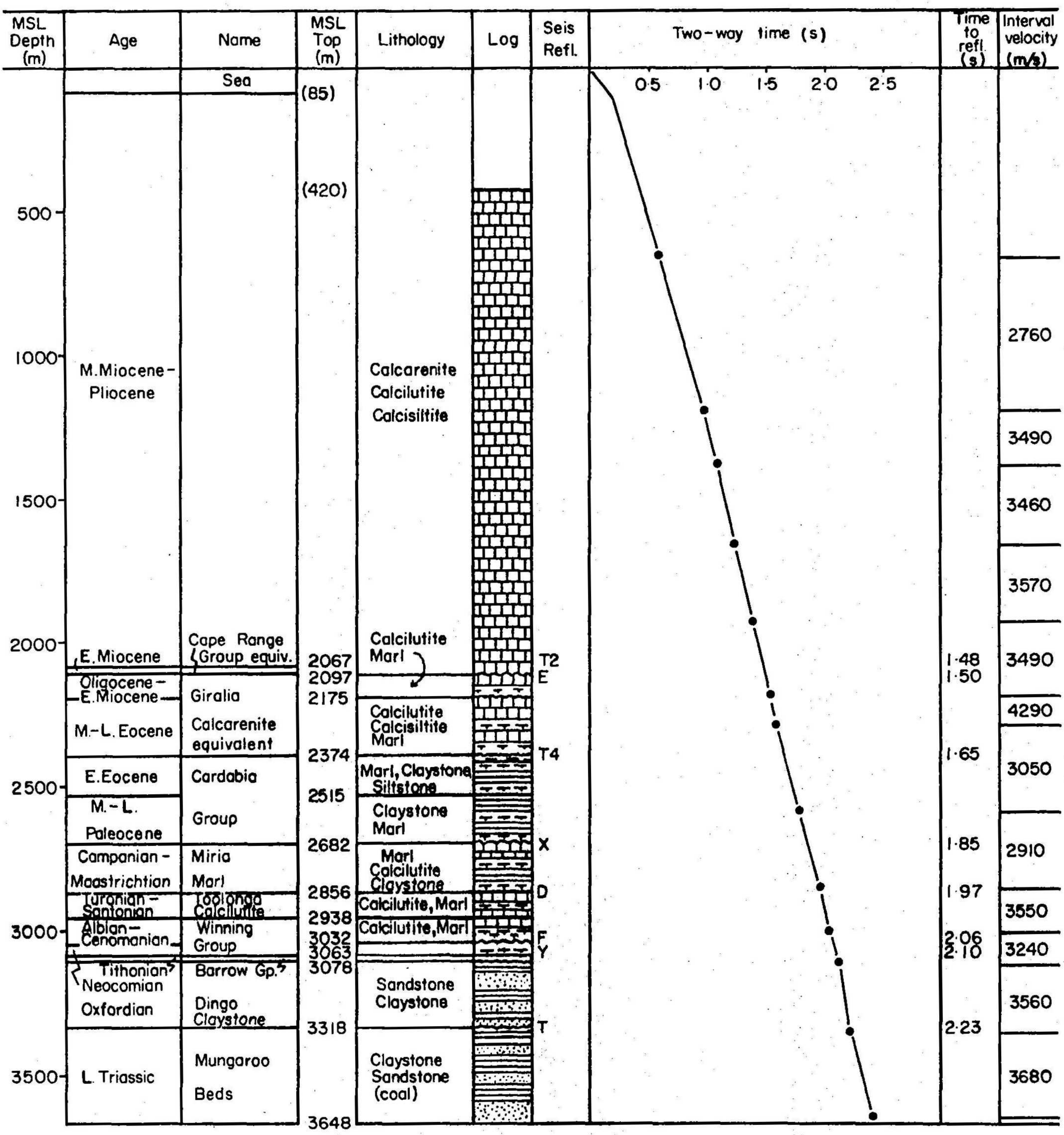
88

WAPET NORTH TRYAL ROCKS No. I LOG

RECORD No 1975/158

E50/B8-44A

FIG. D



Note : Lithological key on Figure 3

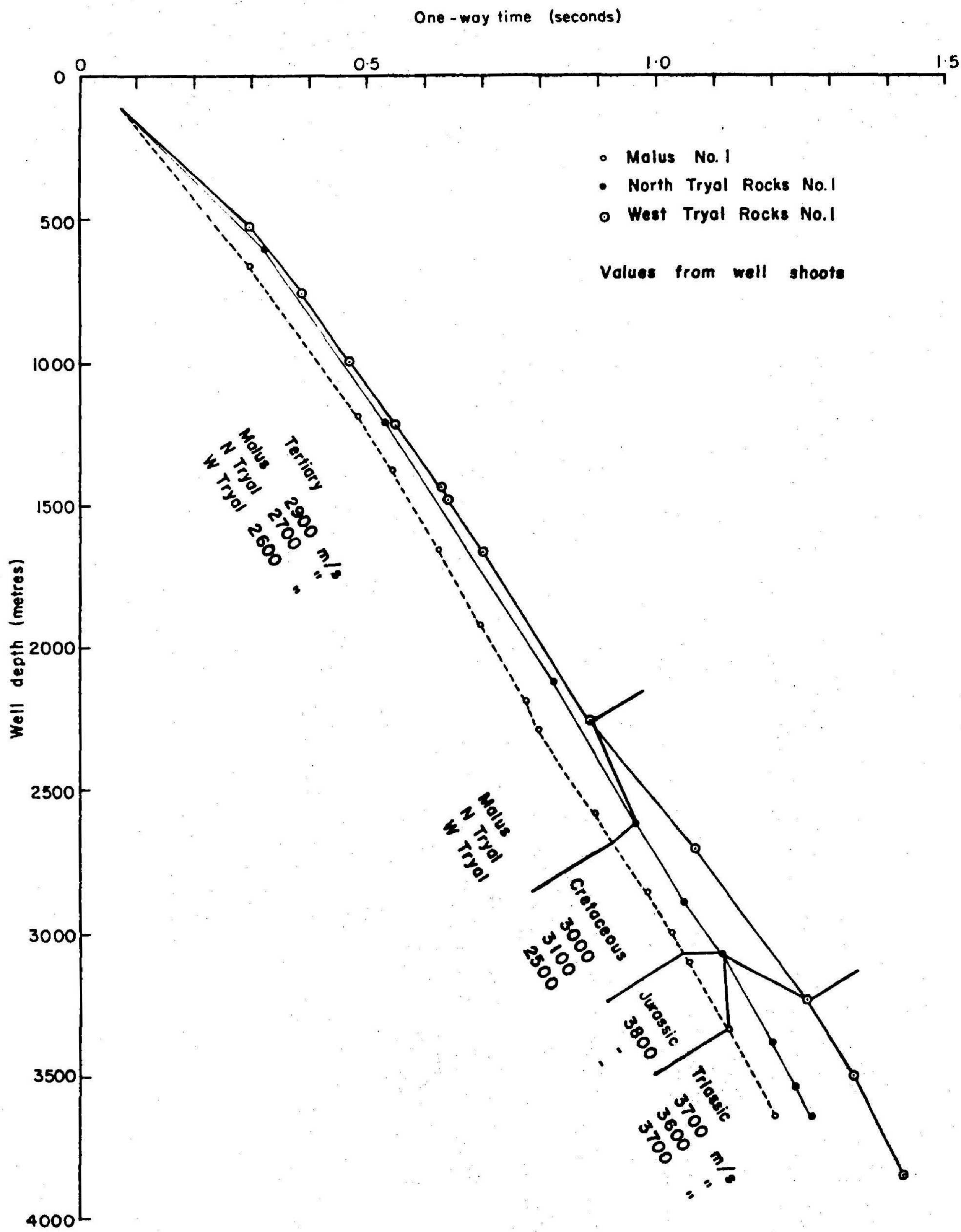
BOC MALUS No.1 LOG

RECORD No 1975/158

E50/B8-45A

89

FIG. E



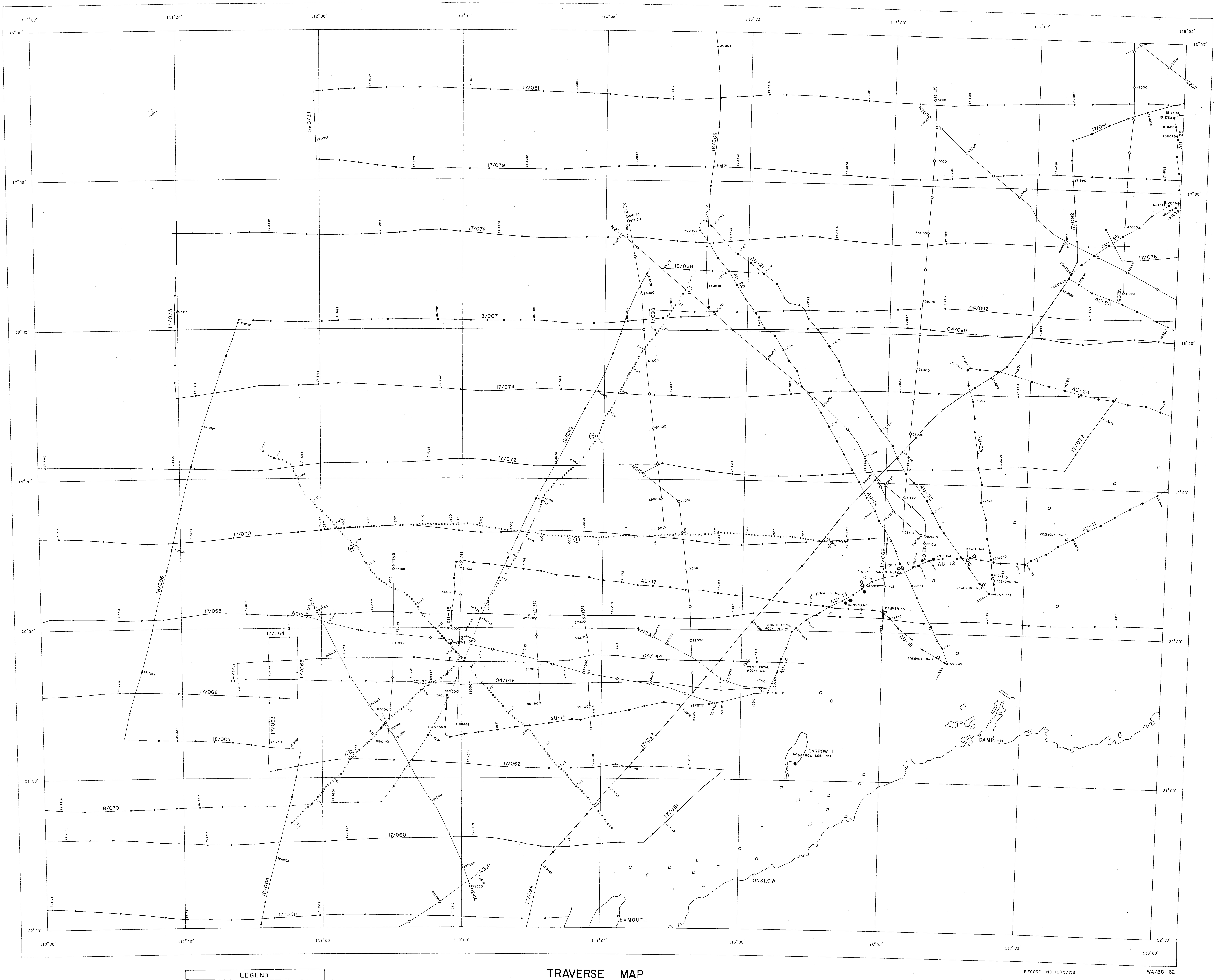
TIME – DEPTH CURVES FOR WEST TRYAL ROCKS No. I, NORTH TRYAL ROCKS No. I AND MALUS No. I WELLS

90

RECORD No 1975/158

E 50 / B8-46 A

EXMOUTH PLATEAU



TRAVERSE MAP

RECORD NO. 1975/158

WA/B8-62

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

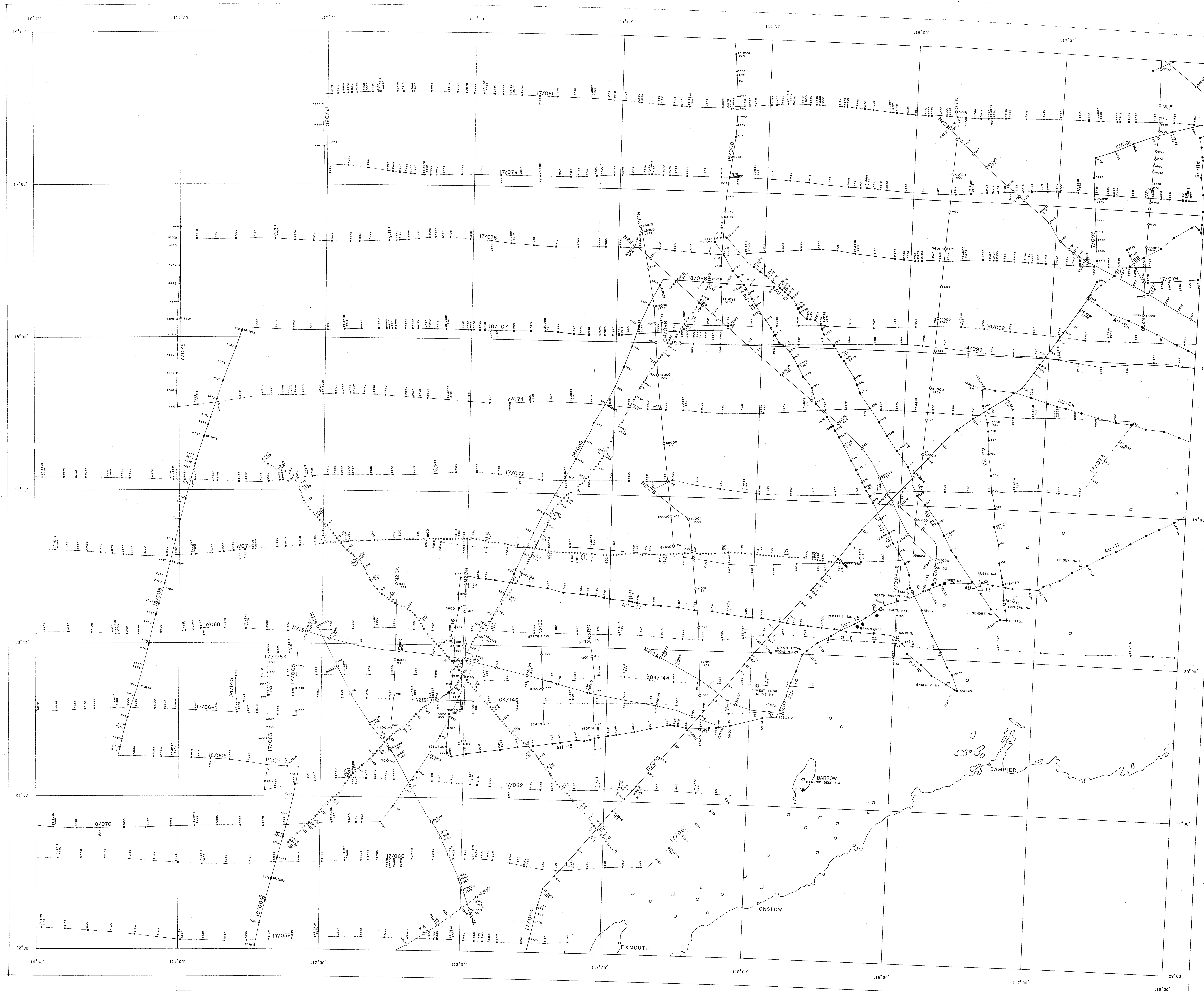
LEGEND	
	BMR, 1968 & 1972
	Shell, 1973
	Esso, 1972
	Gulf, 1973

- Oil well
- Gas well
- Abandoned well

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1000000

EXMOUTH PLATEAU

PLATE 2A



LEGEND	
	BMR, 1968 & 1972
	Shell, 1973
	Esso, 1972
	Gulf, 1973

- Oil well
- Gas well
- Abandoned well

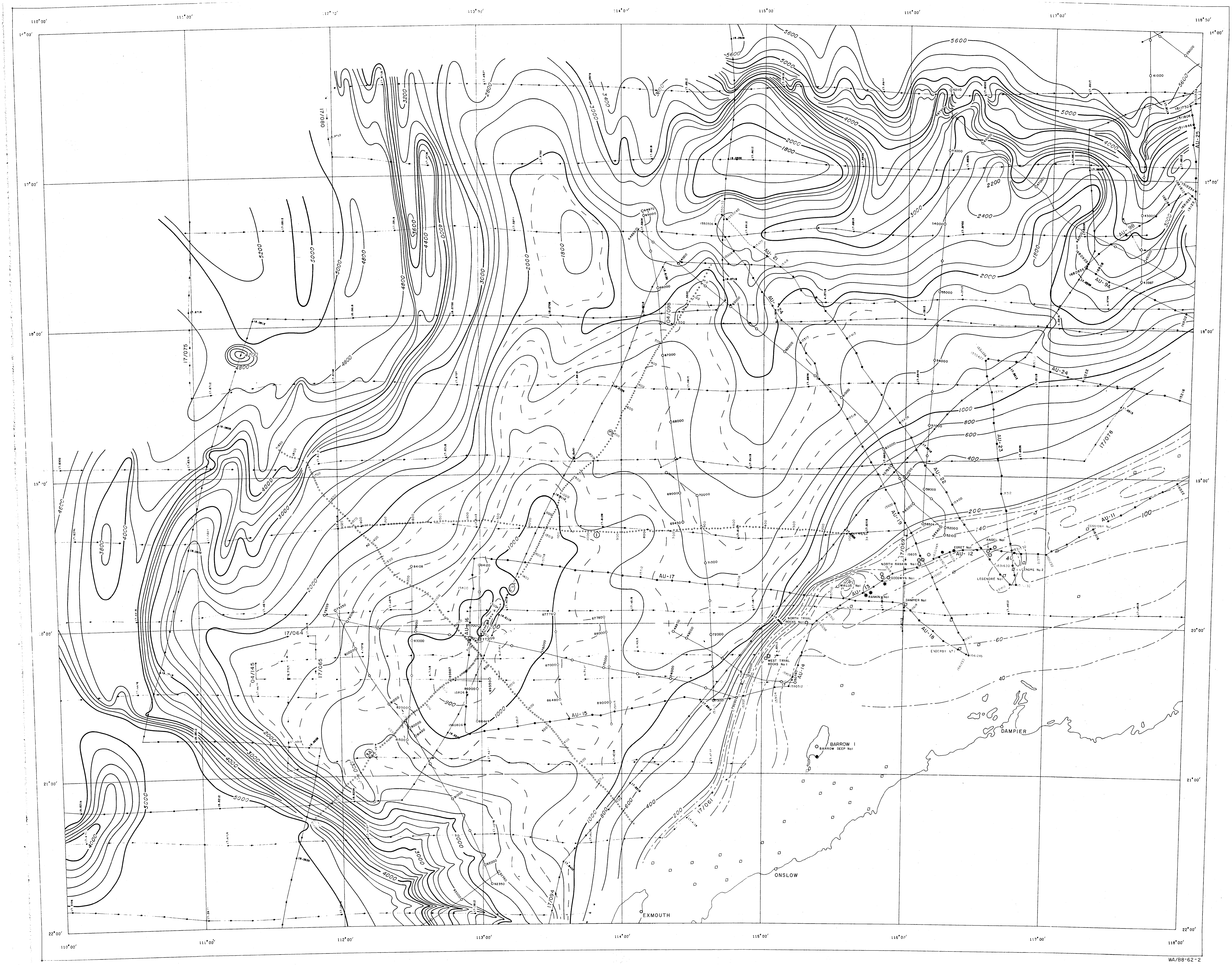
BATHYMETRIC DATA MAP

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

RECORD NO. 1975/158

WA/B8-62-1

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1000000



WA/88-62-2

BATHYMETRIC CONTOUR MAP

PLATE 2B

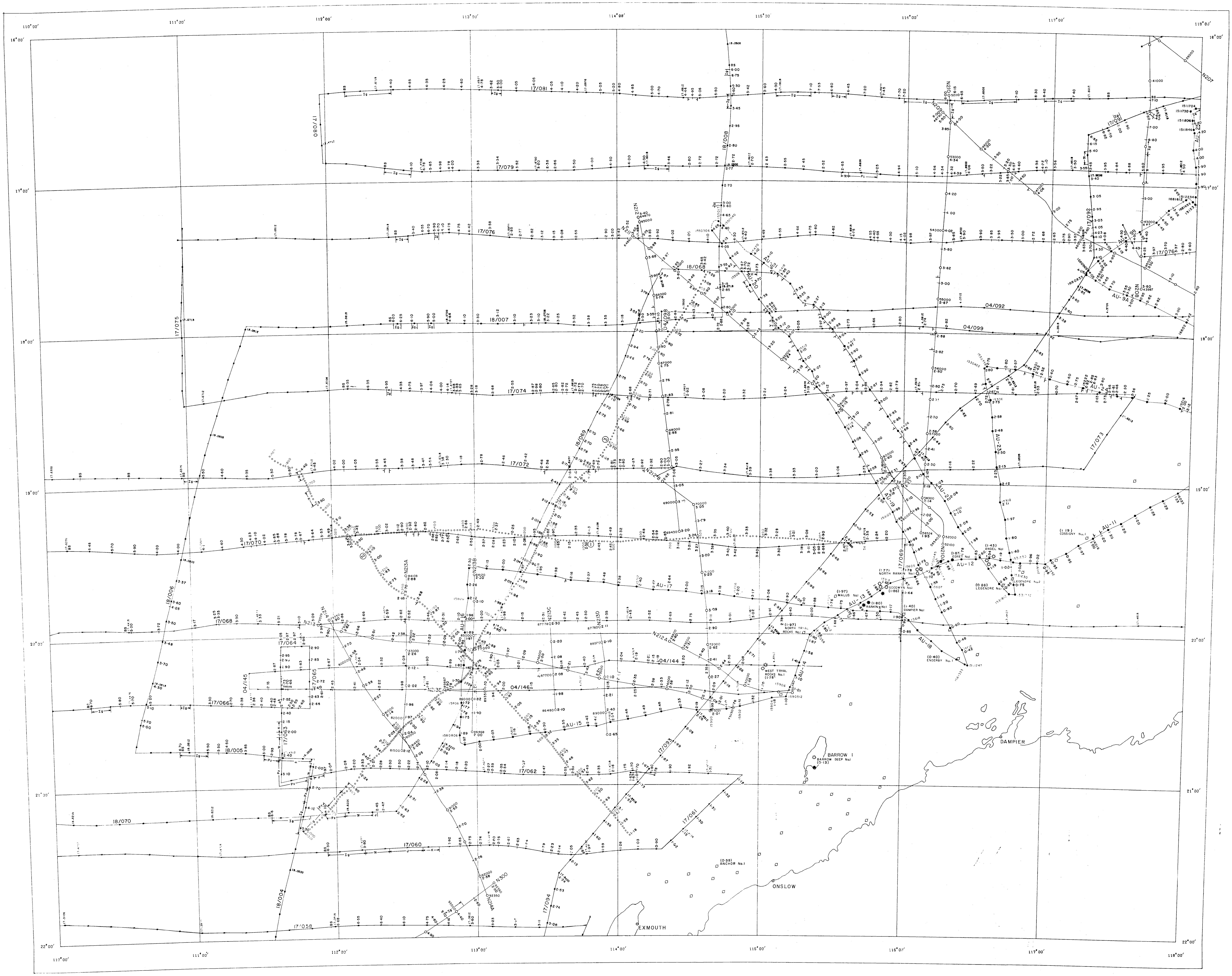
KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS

LEGEND

- BMR, 1968 & 1972
- Shell, 1973
- Esso, 1972
- Gulf, 1973
- Thousand metre contour

- ● Oil well
- ☼ Gas well
- Ø Abandoned well



STRUCTURAL DATA MAP

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

SENONIAN STRUCTURE
(TIME TO HORIZON C)

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1000000

LEGEND

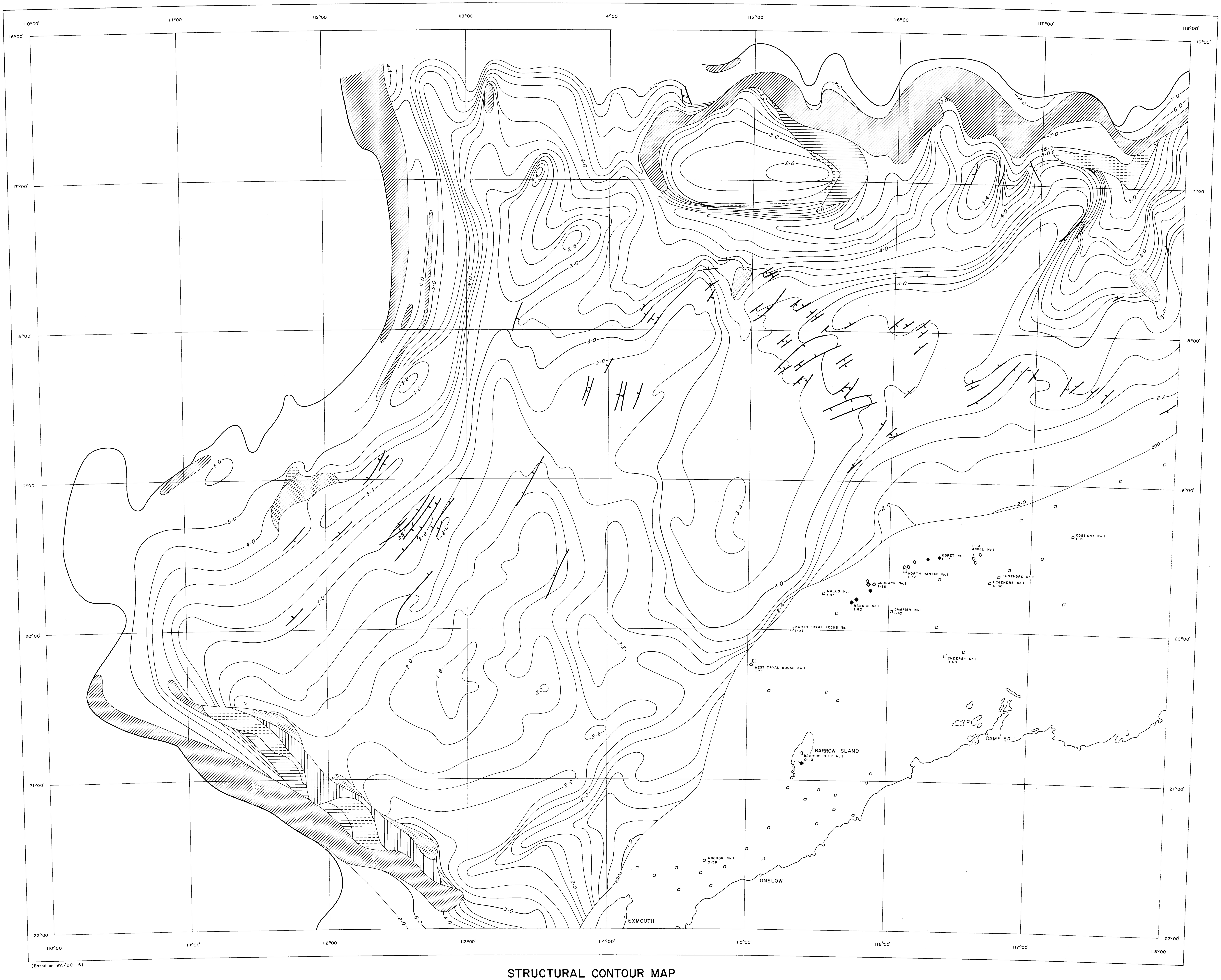
- BMR, 1968 & 1972
- Shell, 1973
- Esso, 1972
- Gulf, 1973

(0·13) Two-way time (s) to Senonian in wells
Oil well
Gas well
Abandoned well

BS Base of continental slope
Fault
K Cretaceous outcrop
J Jurassic outcrop
Tr Triassic outcrop
Pz Palaeozoic outcrop
Ig Igneous outcrop

RECORD 1975/158

WA/88-89



(Based on WA/80-16)

STRUCTURAL CONTOUR MAP

KILOMETRES 20 0 20 40 60 80 KILOMETRES

SENONIAN STRUCTURE
(TIME TO HORIZON C)

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1 000 000

1·53 Two-way time to Santonian in wells
Oil well
Gas well
Abandoned well

—3·0— Contours at 2·0s two-way time interval
—1·8— Contours at 0·2s two-way time interval
Fault with small displacement
Base of continental slope

OUTCROP

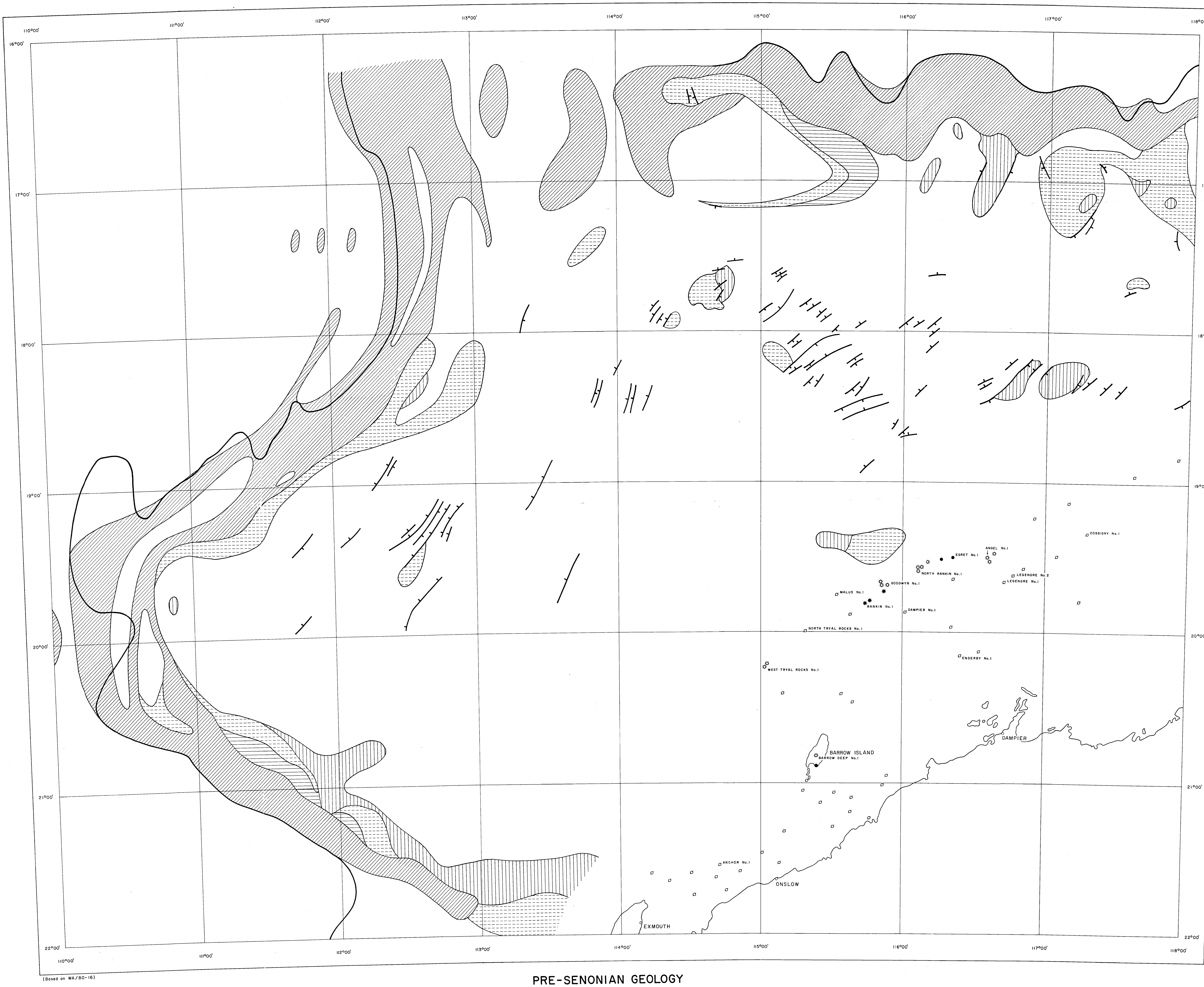
Cretaceous | Triassic | Igneous
Jurassic | Palaeozoic

RECORD NO.1975/158

WA/B8-68

EXMOUTH PLATEAU

PLATE 3C



(Based on WA/B0-16)

PRE-SENONIAN GEOLOGY

KILOMETRES 20 0 20 40 60 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1 000 000

● Oil well
☼ Gas well
ø Abandoned well

Fault with small displacement
Base of continental slope

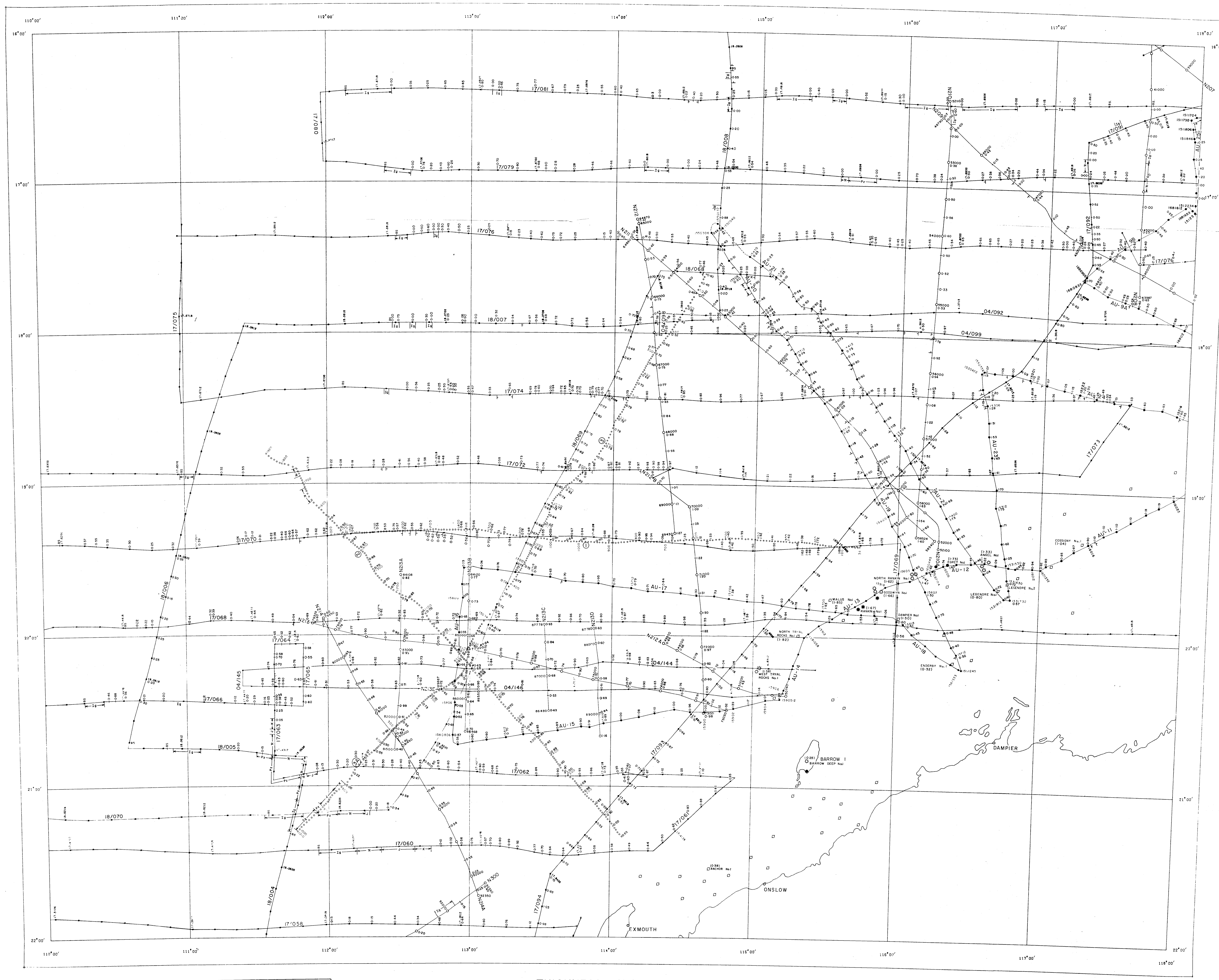
Cretaceous (pre Senonian) sediments
Jurassic (pre Neocomian) sediments
Triassic sediments
Palaeozoic sediments
Igneous rocks

RECORD NO. 1975/158

WA/B8-70

EXMOUTH PLATEAU

PLATE 4A



THICKNESS DATA MAP

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

SENONIAN - CAINOZOIC THICKNESS
(TIME FROM SEABED TO HORIZON C)

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1000000

LEGEND

- BMR, 1968 & 1972
- Shell, 1973
- Esso, 1972
- Gulf, 1973

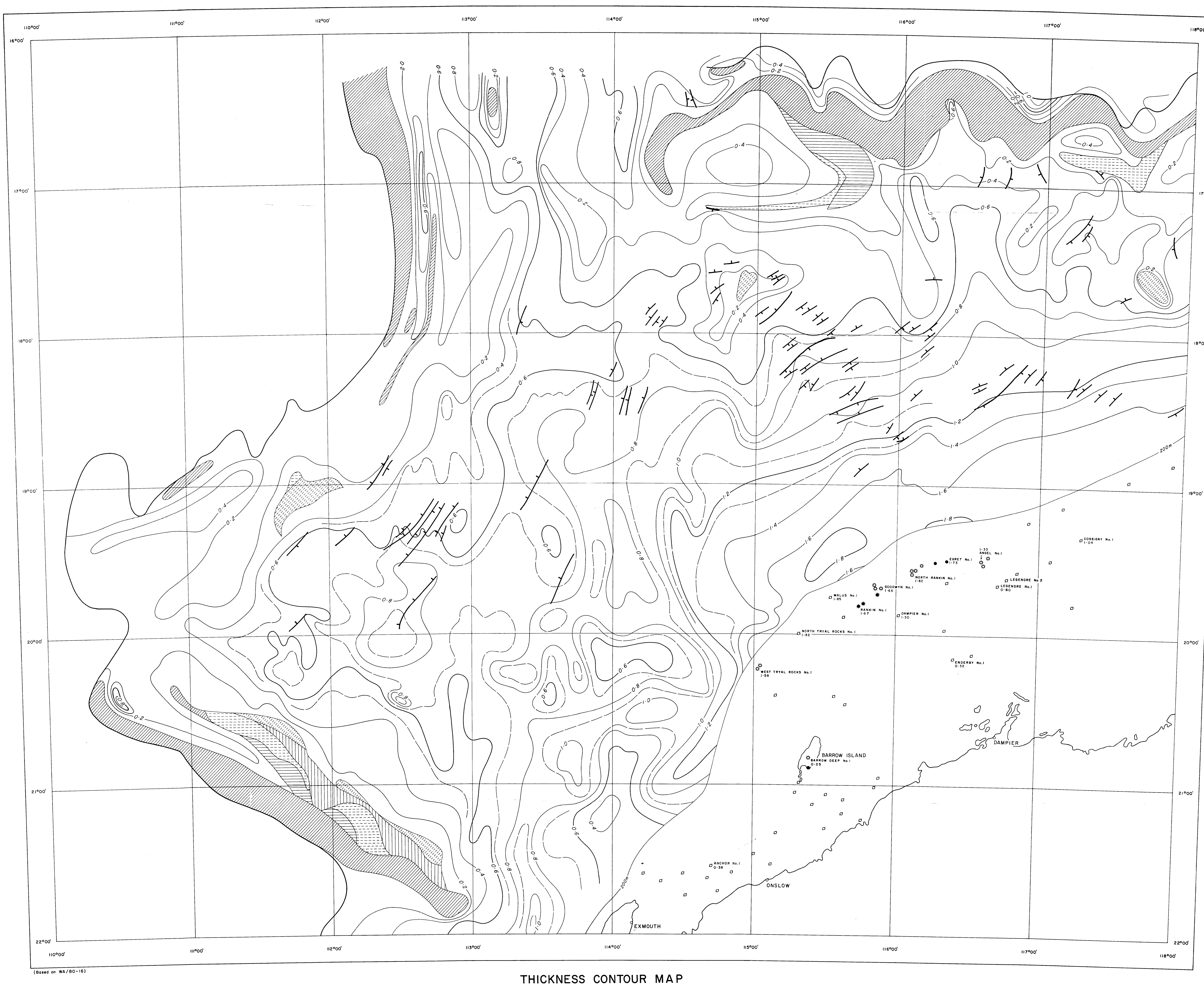
(0·23) Two-way time(s) to Santonian in wells
- ● Oil well
- ☼ Gas well
- ø Abandoned well

BS	Base of continental slope
⊥	Fault
K	Cretaceous outcrop
J	Jurassic outcrop
Ʀ	Triassic outcrop
Pz	Palaeozoic outcrop
Ig	Igneous outcrop

RECORD NO. 1975/158

WA/B8-90

EXMOUTH PLATEAU



(Based on WA/80-16)

THICKNESS CONTOUR MAP

KILOMETRES 20 0 20 40 60 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1 000 000

1·53 Two-way time to Santonian in wells
● Oil well
☼ Gas well
ø Abandoned well

SENONIAN-CAINOZOIC THICKNESS
(TIME FROM SEABED TO HORIZON C)

-1·2- -1·0- Contours at 0·2s two-way time
— — Formlines
Fault with small displacement
Base of continental slope

OUTCROP

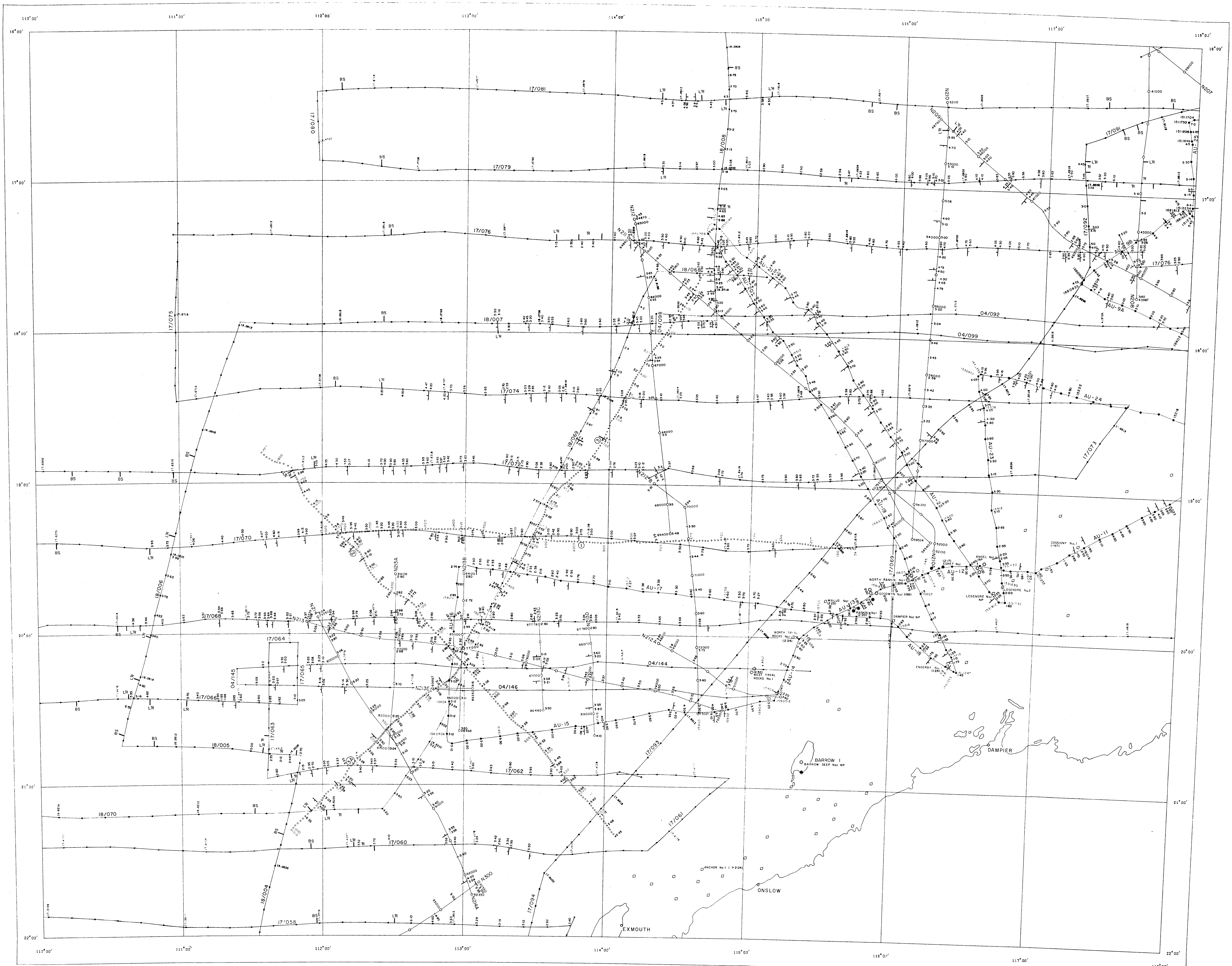
Cretaceous | Triassic | Igneous
Jurassic | Palaeozoic

RECORD NO. 1975/158

WA/88-69

EXMOUTH PLATEAU

PLATE 5A



GENERALIZED STRUCTURAL DATA MAP

TOP TRIASSIC STRUCTURE

(TIME TO HORIZON F)

LEGEND

- BMR, 1968 & 1972
- Shell, 1973
- Esso, 1972
- Gulf, 1973

(2·13) Two-way time (s) to Top Triassic in wells (NP=not present)

- Oil well
- Gas well
- Abandoned well

BS Base of continental slope

Fault

TR Triassic outcrop

L'R Limit of Triassic

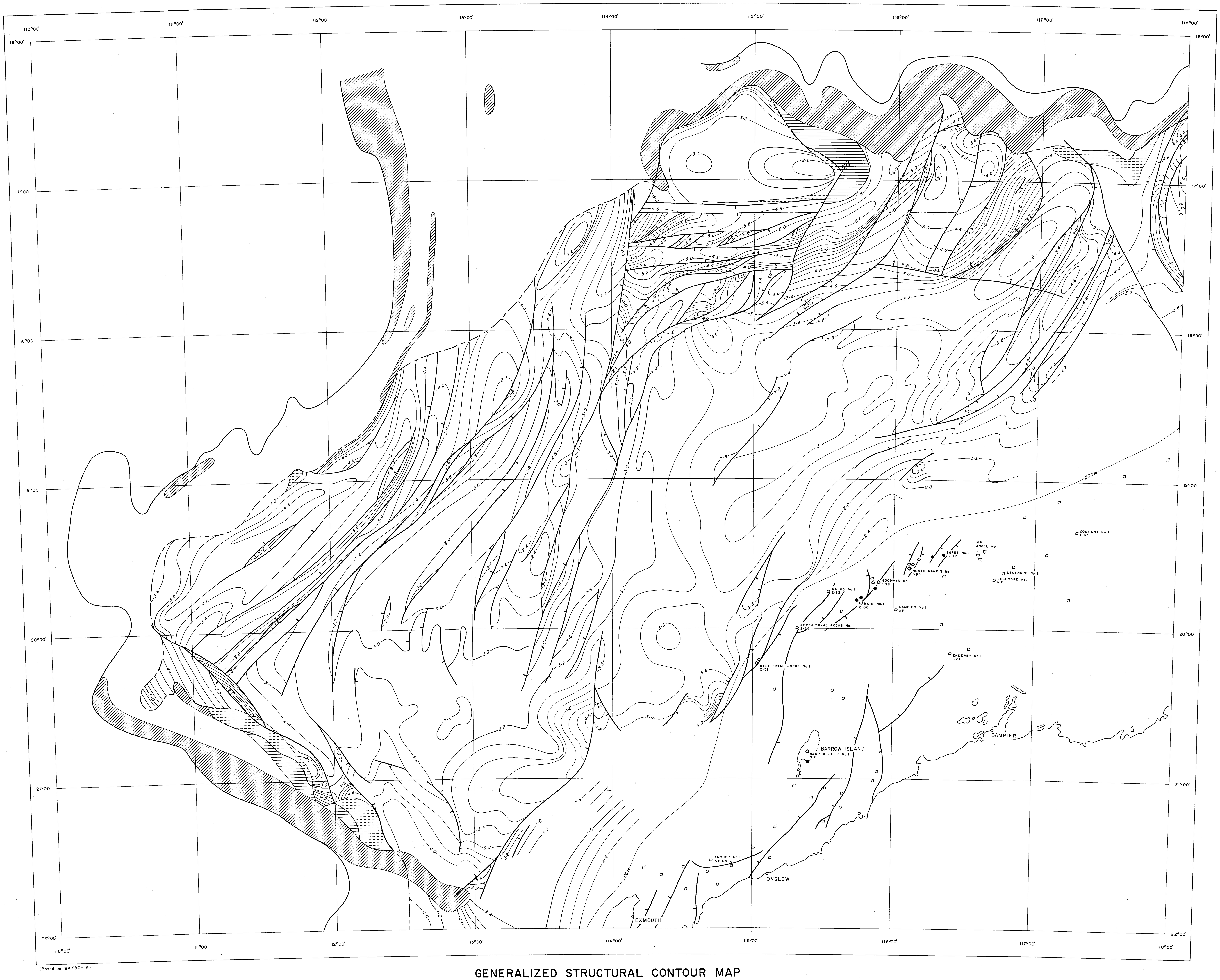
APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1000000

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

RECORD No. 1975/158

EXMOUTH PLATEAU

PLATE 5B



(Based on WA/B0-16)

GENERALIZED STRUCTURAL CONTOUR MAP

KILOMETRES 20 0 20 40 60 80 KILOMETRES

TOP TRIASSIC STRUCTURE

(TIME TO HORIZON F)

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1 000 000

- 1·67 Two-way time to Top Triassic in wells
- Oil well
- Gas well
- Abandoned well

- Fault with important transcurrent movement
- 3·2 Contours at 0·2s two-way time interval
- 3·0 Contours at 2·0s two-way time interval
- Fault zone
- Monocline grading to fault
- Base of continental slope
- Limit of Triassic area

Outcrops

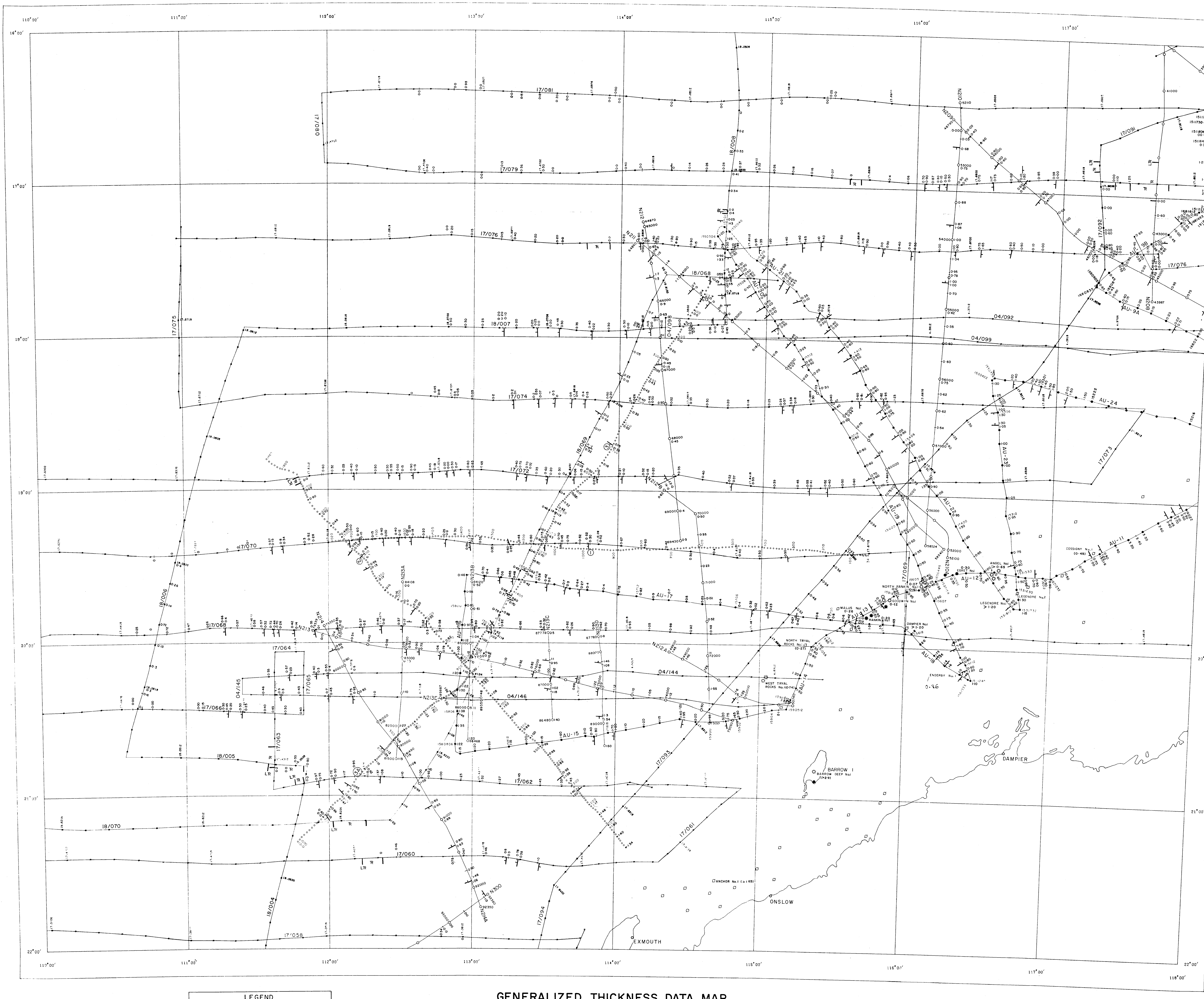
- Igneous
- Paleozoic
- Triassic

RECORD NO. 1975/158

WA/B8-71

EXMOUTH PLATEAU

PLATE 6A



GENERALIZED THICKNESS DATA MAP

KILOMETRES 10 0 10 20 30 40 50 60 70 80 KILOMETRES

JURASSIC - SENONIAN THICKNESS

(TIME FROM HORIZON C TO F)

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1000000

LEGEND

- BMR, 1968 & 1972
- Shell, 1973
- Esso, 1972
- Gulf, 1973

(0·13) Two-way time (s) to Cretaceous + Triassic in wells
- Oil well
- Gas well
- Abandoned well

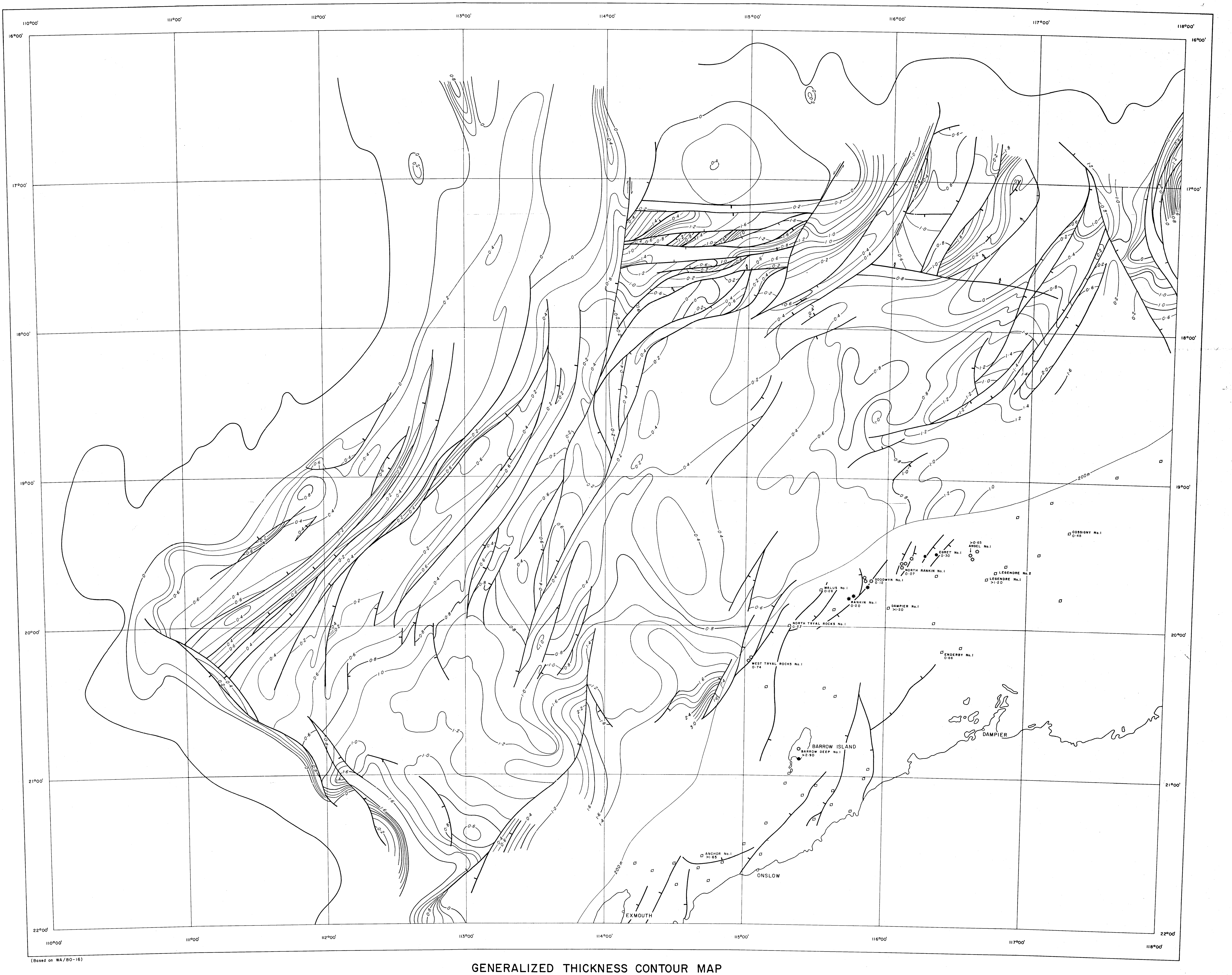
BS Base of continental slope
Fault
ꞦR Triassic outcrop
LR Limit of Triassic

RECORD No 1975/158

WA/88-96

EXMOUTH PLATEAU

PLATE 6B



(Based on WA/80-16)

GENERALIZED THICKNESS CONTOUR MAP

KILOMETRES 20 0 20 40 60 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH
AUSTRALIA 1:1 000 000

0·74 Two-way time interval in wells
● Oil well
☼ Gas well
ø Abandoned well

JURASSIC-SENONIAN THICKNESS
(TIME FROM HORIZON C TO F)

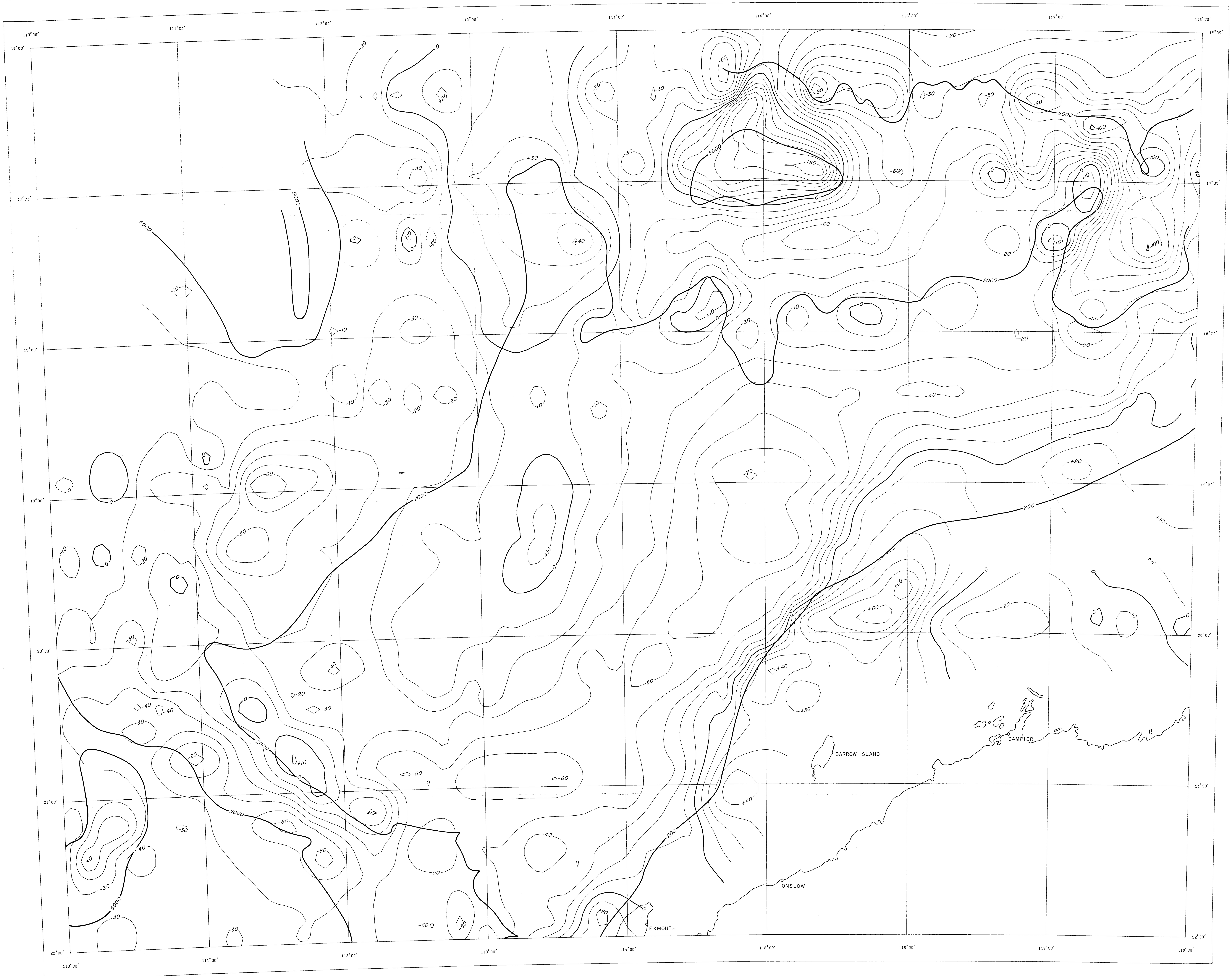
Fault with important transcurrent movement
—1·4— Contours at 0·2s two-way time interval
—1·6— Contours at 0·8s two-way time interval
Fault zone
Monocline grading to fault
Base of continental slope

RECORD NO. 1975/158

WA/B8-72

PLOTTED 31/01/75

AUSTRALIA 1 1000000



KILOMETRES 20 0 20 40 60 80 KILOMETRES

EXMOUTH PLATEAU

FREE-AIR ANOMALIES

—0— —10— Isogal (milligals)
—200— Isobath (metres)

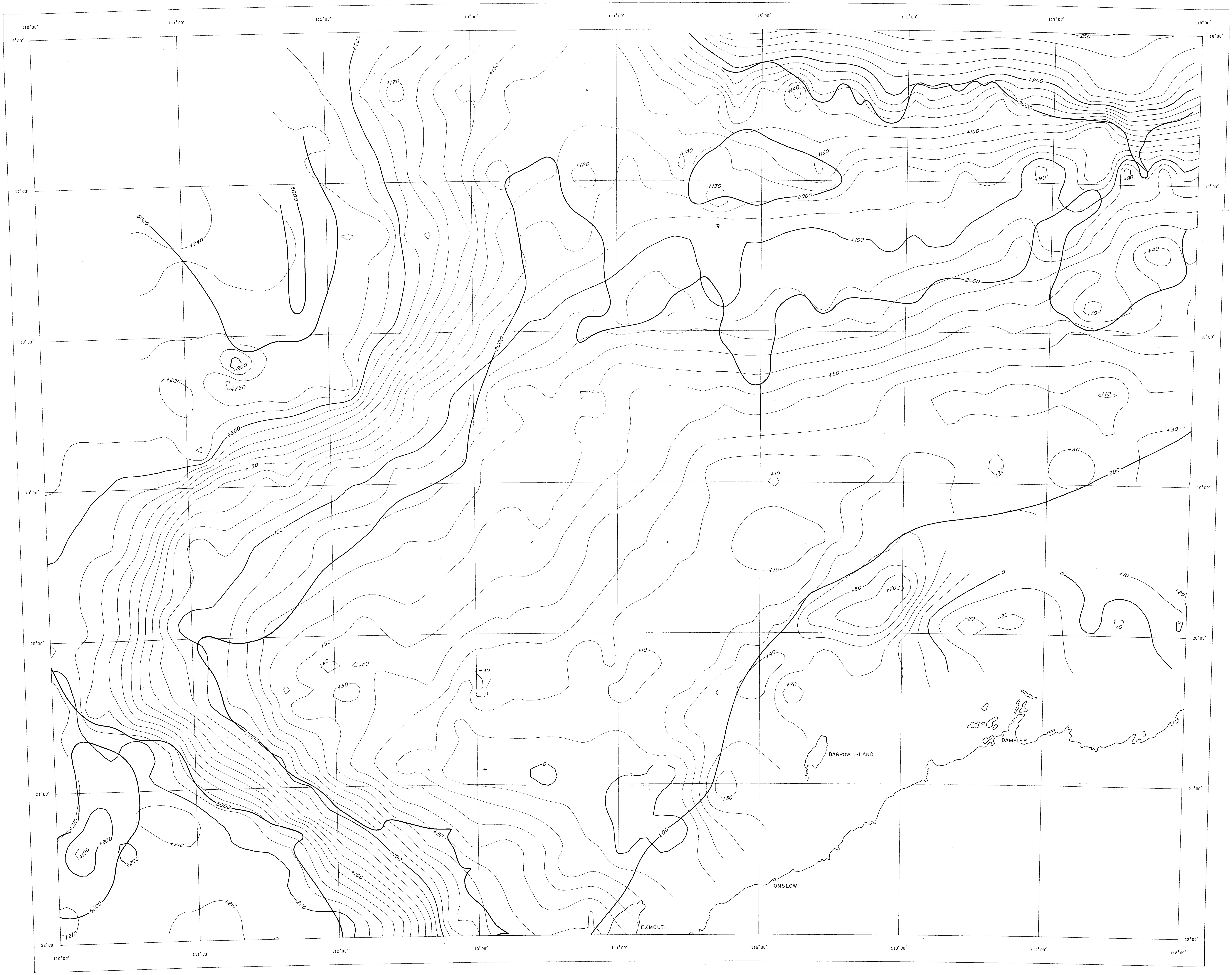
APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18 0 AND 36 0 SOUTH
AUSTRALIA 1:1 000 000

RECORD NO. 1975/158

WA/88-74

PLOTTED 30/01/75

AUSTRALIA 1 1000000



KILOMETRES 20 0 20 40 60 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

EXMOUTH PLATEAU

BOUGUER ANOMALIES

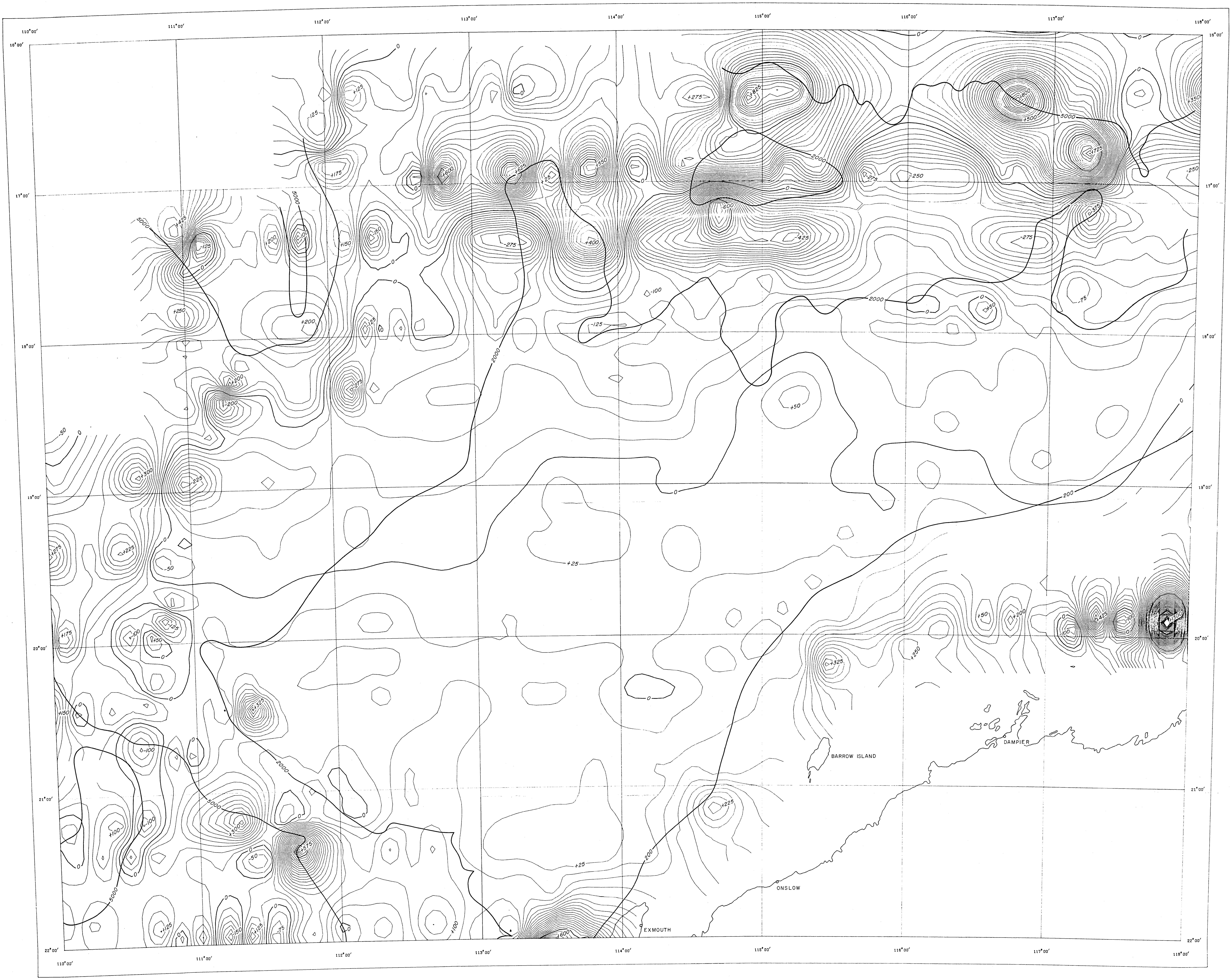
Bouguer density = 2·2 g/cm³
0 / +10 Isogal (milligals)
200 Isobath (metres)

RECORD NO. 1975/156

WA/88-75

PLOTTED 21/11/74

AUSTRALIA 1 1000000



KILOMETRES 20 0 20 40 60 80 KILOMETRES

APL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

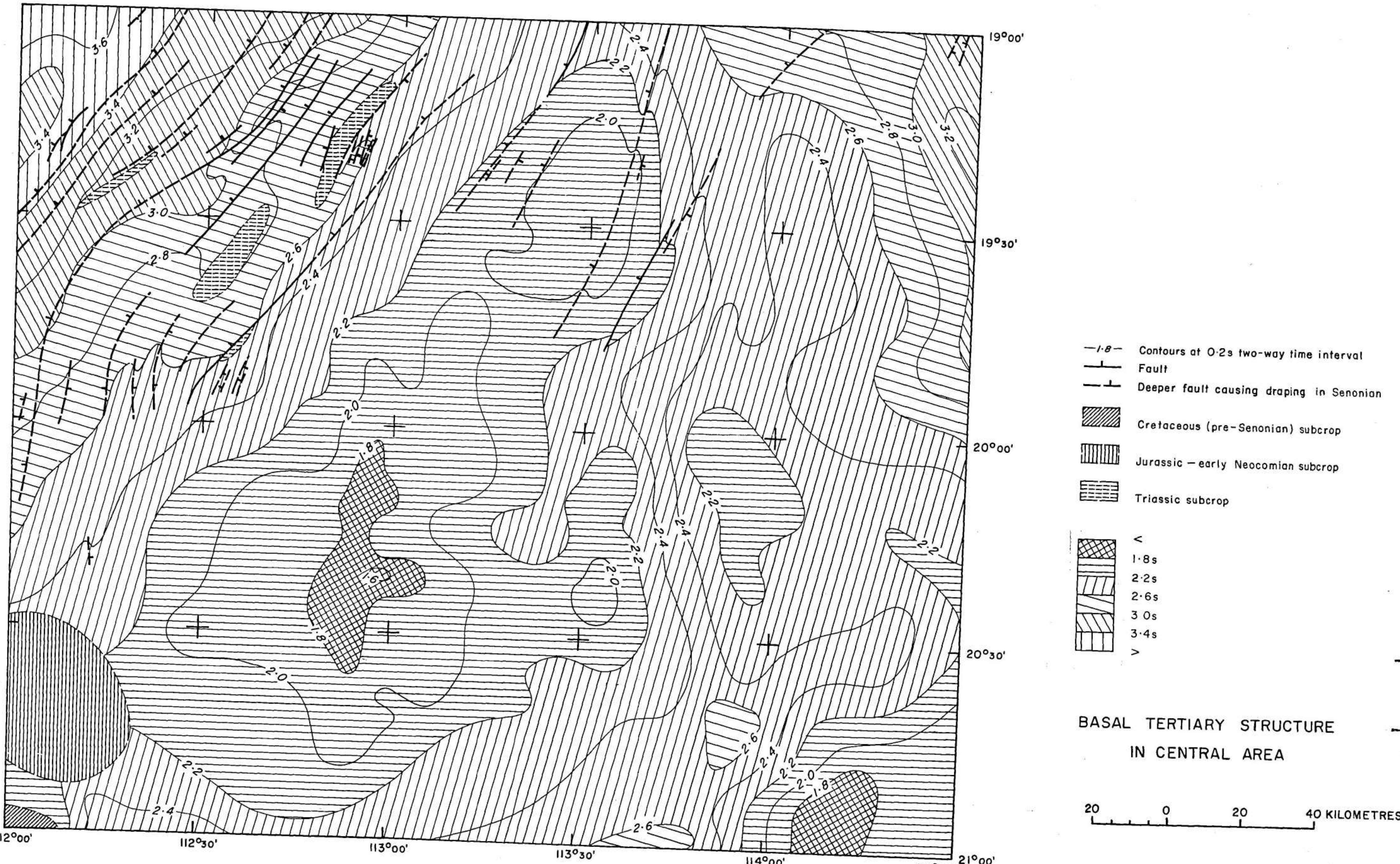
EXMOUTH PLATEAU

MAGNETIC ANOMALIES

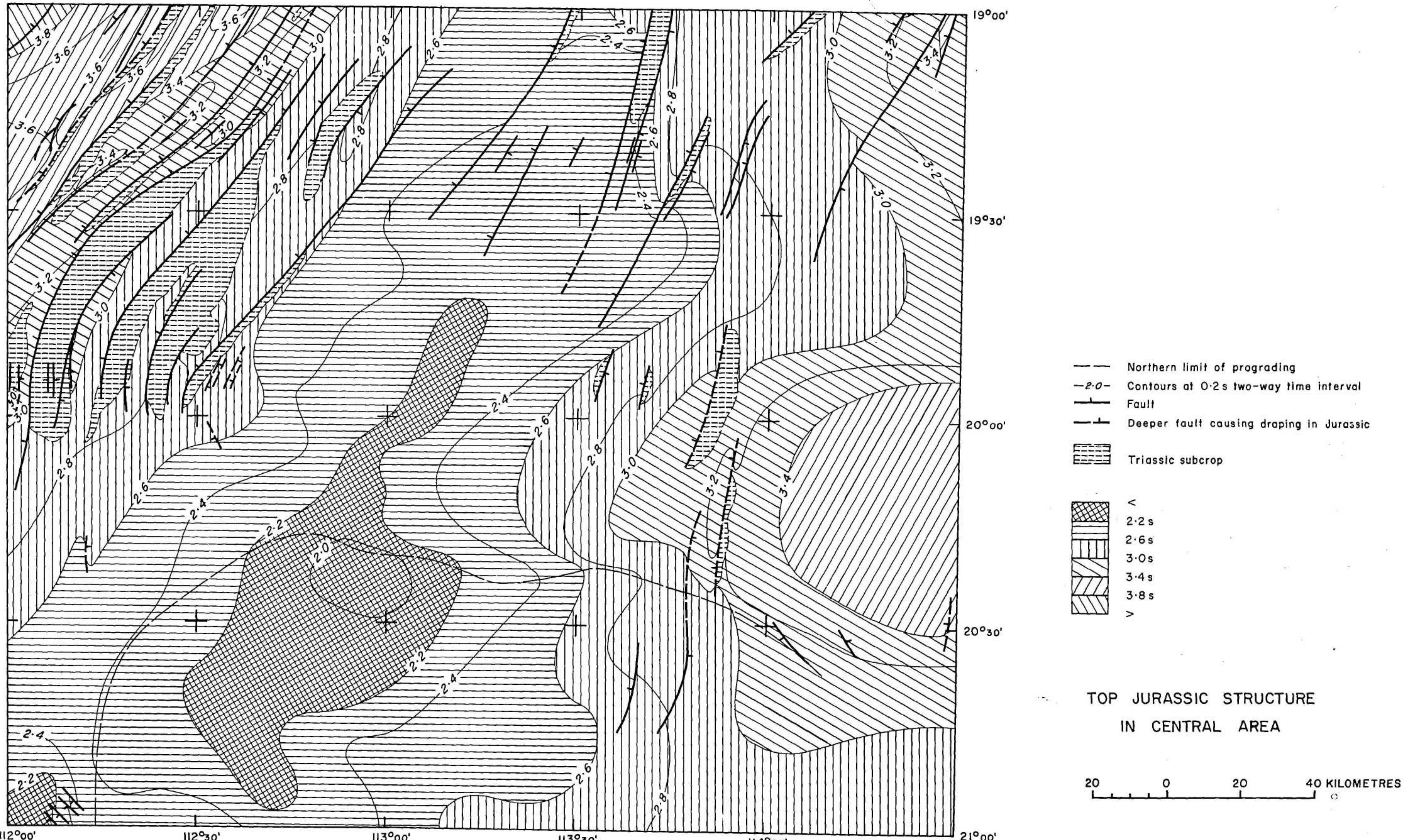
Contour interval 25 nanoTeslas
—0— —+25— Magnetic contours (nT)
—200— Isobath (metres)

RECORD No 1975/158

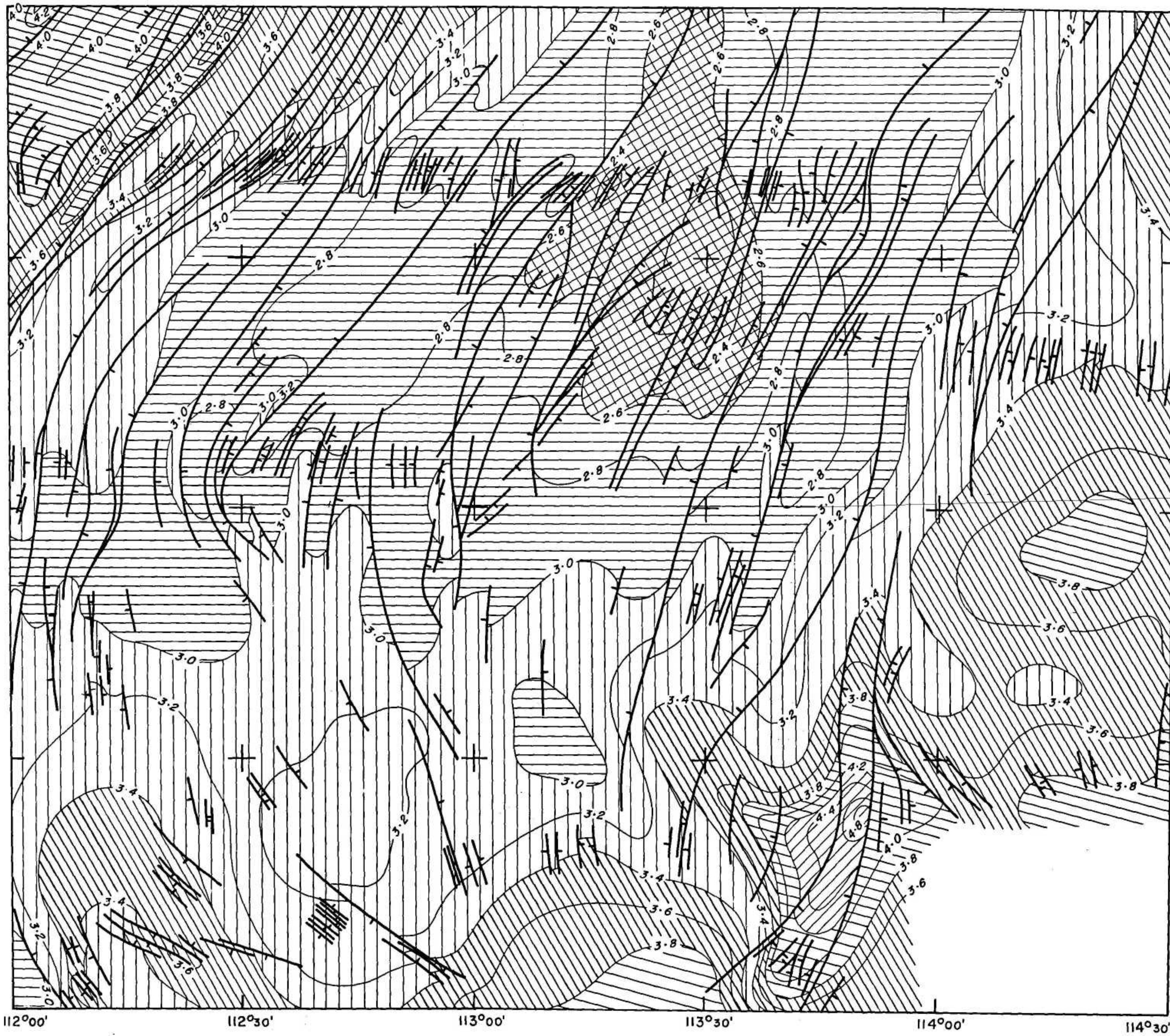
WA/88-73



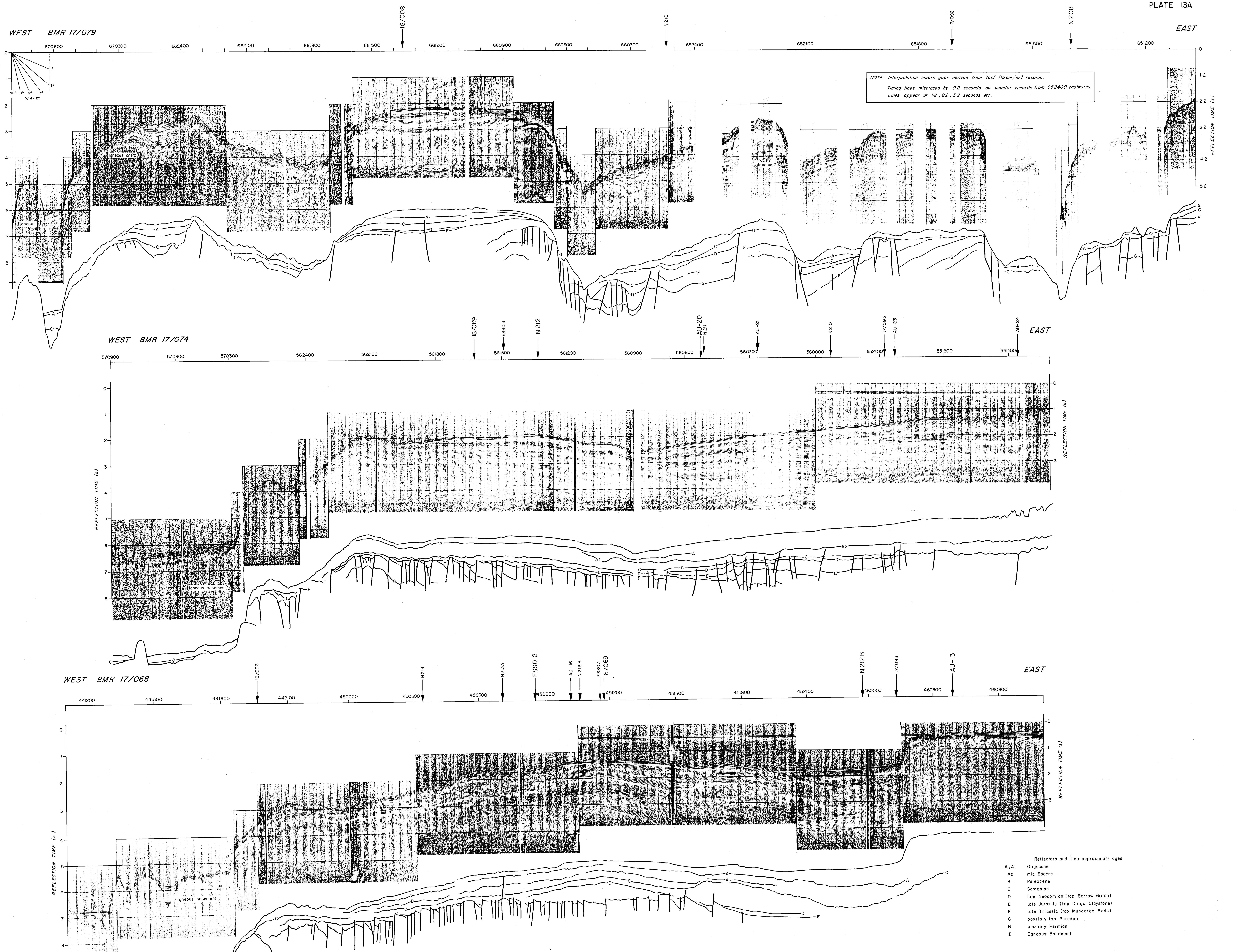
BASAL TERTIARY STRUCTURE IN CENTRAL AREA



TOP JURASSIC STRUCTURE IN CENTRAL AREA



TOP TRIASSIC STRUCTURE IN CENTRAL AREA

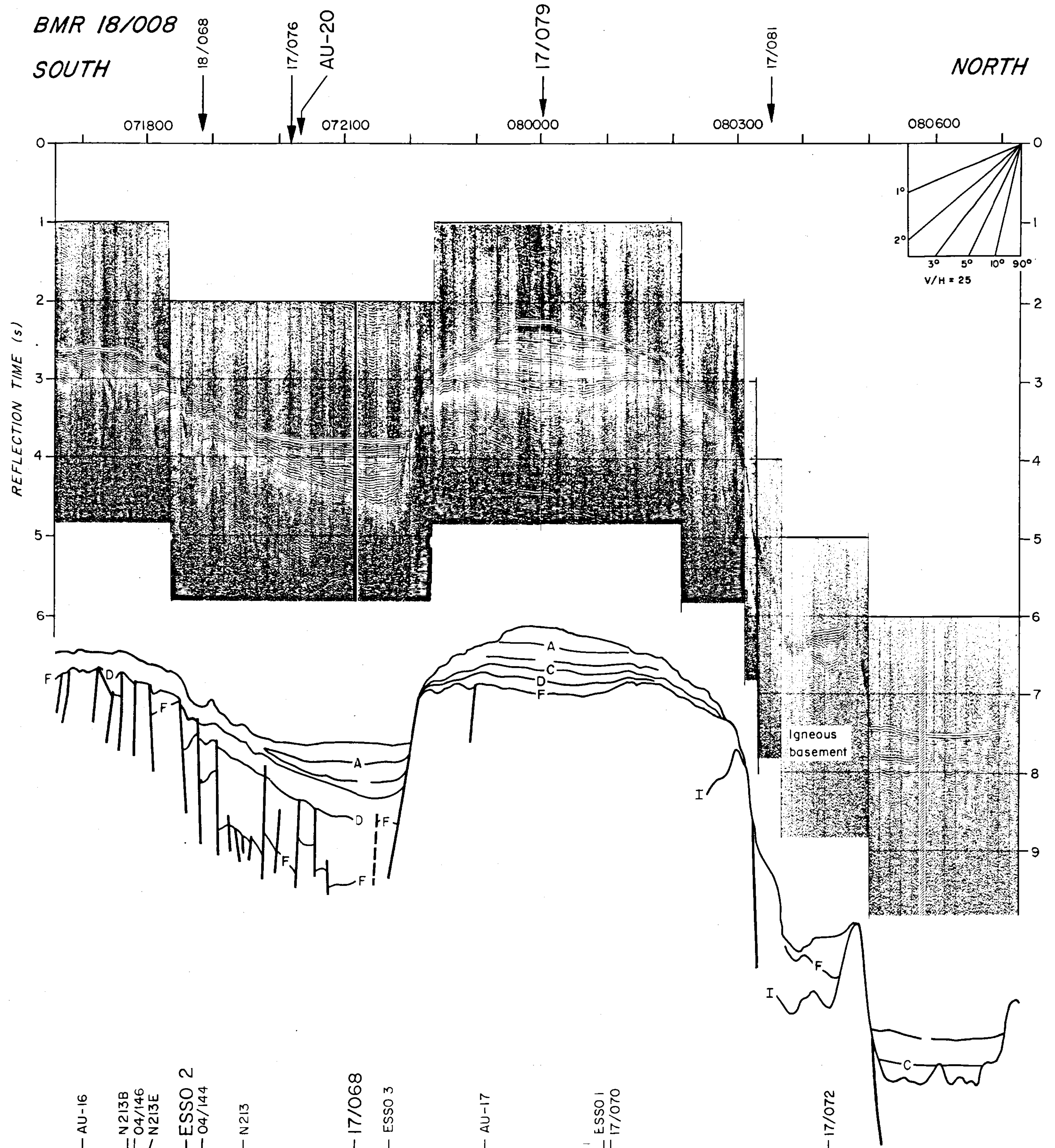


INTERPRETATION OF BMR SEISMIC SECTIONS, EAST-WEST LINES

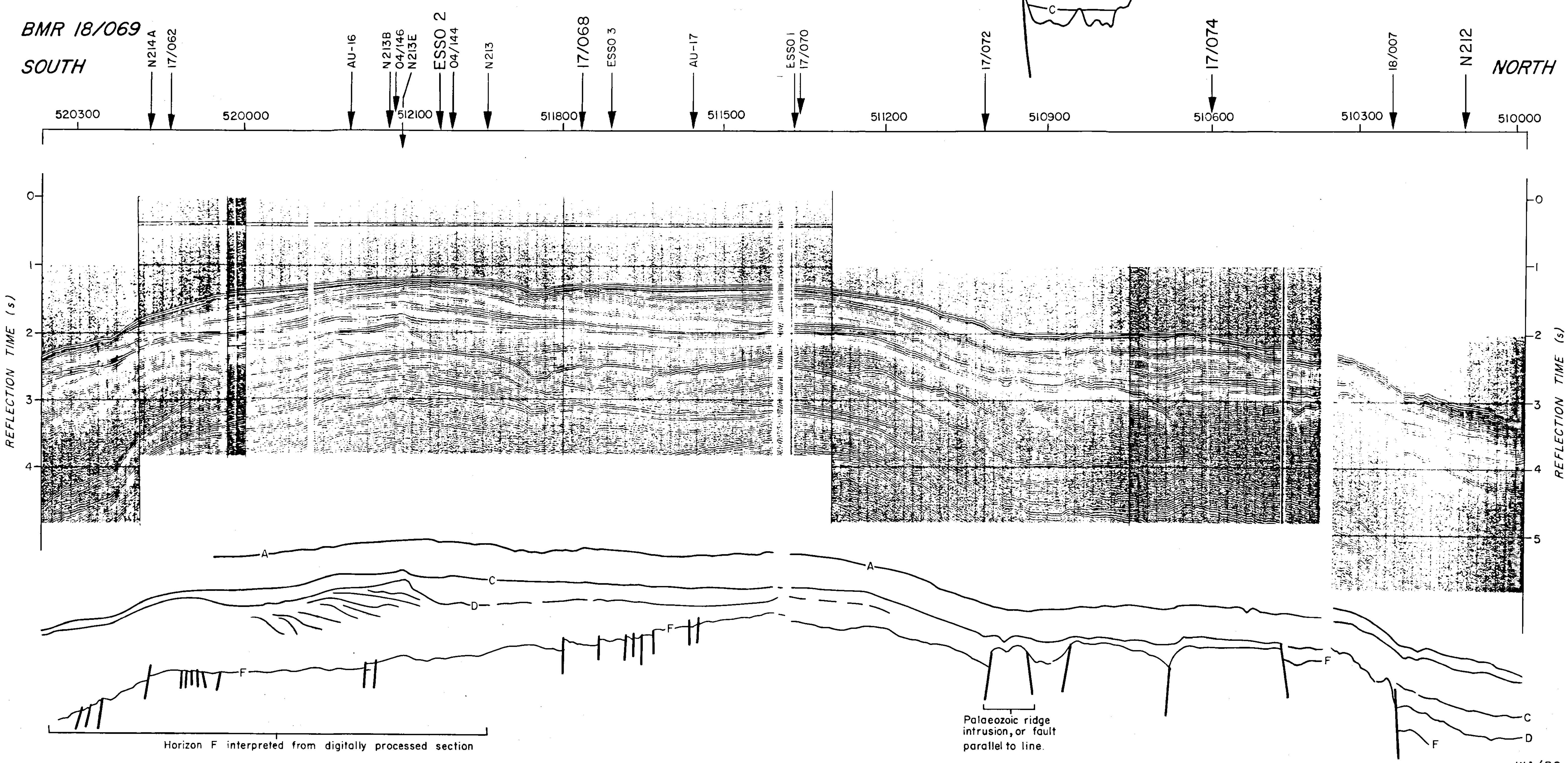
RECORD No. 1975/158

WA/B8-80

INTERPRETATION OF BMR SEISMIC SECTIONS, NORTH-SOUTH LINES



Note: Reflectors explained in Plate 13A



WA/B8-81

SHELL N212 & N212B

Note: Reflectors explained in Plate 13A

RECORD No 1975/158

WA/B8-82

PLATE 13D

Note: Reflectors explained in Plate 13A

ESSO 2

RECORD No 1975/158

WA/B8-83

PLATE

Note: Reflectors explained in Plate 13A

GULF AU 12 - 13 - 13B - 14

RECORD No 1975/158


NORTHWEST
18/008
17/076
17/068
04/098
04/099
17/074
17/072
17/093
NORTH RANKIN No1
AU-13
0306
0400
0500
0600
0700
0800
60° 40° 30° 20°
V/H = 4
REFLECTION TIME (S)
0
1
2
3
4
5
6
7
8
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000

PLATE 14

MAGNETIC AND BATHYMETRIC PROFILES

RECORD No 1975/158

WA/B8-87